PN-ACP-347

The Middle East Regional Cooperation Program
(MERC)

AN ANNUAL REPORT

February 1st, 2001 to January 31st, 2002

Submitted to the U.S. Agency for International Development; Bureau for Global Programs, Field Support and Research; Center for Economic Growth and Agriculture Development

Title of the Project:

Water Quality along the Jordan River: A Geochemical Perspective on the Sources of Salts

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Project Number: M20-068

Award Number: TA-MOU-99-M20-068

Section I: Technical Progress

1. Introduction and Research Objectives:

The Jordan River is the largest river in the region. The river originates from three sources; Dan, Banyas and Hasbani, from which it flows through the Upper Jordan River into Lake Tiberias (210*m* below msl). The Lower Jordan River starts at Alumot, downstream from Lake Tiberias, and ends at the Dead Sea in the south (410*m* below msl). The river symbolizes the history of the region. Starting with the Israelites crossing the river, and continuing by the Prophets, Elijah, Elisha, John the Baptist and Jesus Christ all crossed the river in their lifetimes. At present, the Lower Jordan River serves as an international border.

The quality and quantities of water delivered by the Lower Jordan River have been extremely degraded during the last decades. Since the implementation of water supply projects in Israel, Jordan, and Syria, no fresh surface water flows into the river (except for negligible springs and rare flood events). The historical annual volume that drained to the Dead Sea through the Jordan River was 1200 MCM. It included water from the Sea of Galilee (500 MCM/year), the Yarmok River (500 MCM/year), and local runoffs. After damming the outflow from the Sea of Galilee and the establishment of Israel's National Water Carrier during the 60's, the outflow from the lake reduced to about 70 MCM/year during the 1970's, and zero during the 1990's. Only on rare occasions of extremely wet years the Dagania Dam releases water from the lake to the lower Jordan River. In order to reduce the salinity of the Sea of Galilee, natural saline springs are diverted through the "saline carrier" to the lower Jordan River (20 MCM/year). Together with sewage effluents (6-10 MCM/year), these waters form today's source of the northern part of the lower Jordan River. The Yarmok River joins the river 7 km downstream from the Sea of Galilee. The discharge of this major tributary to the Jordan River was drastically reduced when its water was diverted in the 60's to the King's Abdalla Canal for irrigation and household usages. Similarly to the Sea of Galilee, the Yarmouk contribution to the Jordan River base flow is zero (Hof, 1998; Klein, 1998; Salik, 1998). Currently, only 50-200 MCM/year of mostly poor quality fluids reaches the lower Jordan River (Tahal, 2000) resulting in a significant degradation of water quality. As a result, the available water sources are limited to water from saline springs of Lake Tiberias ('the saline carrier'), natural flows from adjacent saline springs, dumping and leakage of solid and liquid wastes, effluents of fish ponds, and agriculture return flows from adjacent fields.

The river is a resource shared by all peoples in the region. As such, it received a great deal of attention in the peace treaty between Israel and Jordan (October, 1994). Following the agreements between the two countries and the desire to develop the region environment, changes in the operation of the river and its surroundings are expected to take place in the near future. These changes include the desalination of saline water and treatment of sewage and other waste fluids. Al-Weshah (2000) presented recently a water balance calculation. According to his calculation, the total discharge of the river into the Dead Sea is 175 MCM/year. When including the treaty allocations the discharge is reduced to only 60 MCM/year.

The Jordan rift valley serves as a base level to which surface water and ground water drains from both east and west. The river itself serves as the base level to which shallow ground water drains from the valley. The shallow ground water represents a mixture of a variety of end members. Although the expected operational modifications will affect the hydrology and chemistry of the shallow ground water system, we consider it as the more stable system among all other water systems around the river. Better understanding of this complex hydrological and operational system is necessary in order to predict the effect of the expected future changes.

The Jordan Valley basin is part of the Dead Sea rift Valley, an active geological depression with elevations between 210 to 410 meters below sea level. Since late Miocene, several invasions of Mediterranean Sea water into the rift valley created long and narrow lakes from which salt deposits of Mt. Sedom were formed (Zak, 1967). The chemical, boron, and strontium isotopic compositions of brines and saline springs found throughout the Rift Valley reflect chemical evolution and modifications of the original evaporated sea water (Starinsky, 1974). These include sea water evaporation and salt crysallization (e.g., low Na/Cl and high Br/Cl ratios), gypsum precipitation and sulfate reduction (low sulfate), and extensive water-rock interactions such as dolomitization (Ca enrichment and low $^{87}Sr/^{86}Sr$ ratios) and clay adsorption (low B/Li and high $\delta^{11}B$ values) (Starinsky, 1974; Vengosh et al., 1991). The last phase of the fluviatile episode, 100 to 20 Ma BP, was the formation the long and narrow Lake Lisan. Lake Lisan was a hypersaline water body with a sharp density stratification of freshwater overlying hypersaline brines. Since then, large variations occurred, including extensive evaporation, level fluctuations (500-180 bellow sea level) and salinity changes (Yechieli, 1993). The present Jordan River flows through the Lisan Formations that is made of marls and gypsum sediments.

Figure 1 shows the Lower Jordan River region. It also shows the Yarmouk River which marks the border between Israel, Jordan, and Syria. At present, the outlet of Lake Tiberias and the Yarmouk River are blocked by dams. Water from saline springs at the shore of Lake Tiberias is carried by the 'the saline carrier' to Alumot, the starting point of the Lower Jordan River. A total of 20 MCM/year of saline water and about 7 MCM/year of sewage is the initial discharge of the river.

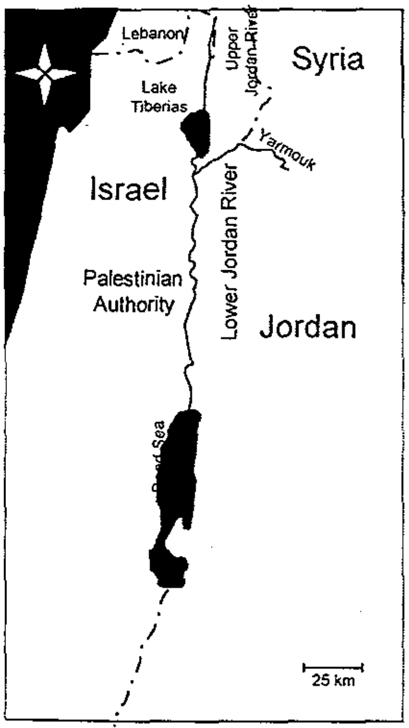


Fig.1 The Lower Jordan River.

The total agricultural irrigated area that drains back to the river was estimated as 440 km^2; 170 km^2 on the west side (Tahal, 2000) and 270 km^2 on the east (Salameh, 1996). The total water consumption for irrigation was estimated as 400 MCM/year in the east side (Salameh, 1996) and about 150 MCM/year in the west side (Tahal, 2000). An analysis of the agricultural influence on the river mass balance is a major challenge of the current study. The above publications have suggested to use a general estimate. They suggested that about 15% flows back to the river. This estimate will be tested against our results.

The project investigates the quantity and quality of water along the Lower Jordan River and evaluates the sources of dissolved salts entering the river. The study identifies, assesses, and quantifies the impacts of the different saline sources on the river salt budget and on the overall water quality. The combination of discharge measurements and chemical analyses of a large number of water samples provides a reliable mass balance and a better understanding of the river system. Since the different contamination sources are distinguished by their chemical and isotopic compositions, the study evaluates the impact of these sources by applying hydrogeochemical and isotopic indicators. The chemical and isotopic data integrated with the regional hydrology and hydrogeology provides the key to understanding the differential impact of the various sources on the quality of the Jordan River.

2. Research Accomplishments

2.1. Overall

During 2001 we were conducting the following activities

1. Collecting additional background information, including previous database and publications on the Jordan River and Jordan Valley.
2. Conducting fieldwork that included discharge measurements in the Jordan River and tributaries inflows, sampling for chemical and isotopic analyses of the Jordan River, sampling inflows, groundwater, and other sources (e.g. fish ponds) in the vicinity of the Jordan River. The data is based on five major fieldtrip (several days each) campaigns for water sampling and several weeks (accumulative) for flow measurements.
3. Major element analyses of the water samples, including measurements of Ca, Mg, K, Na, Cl, SO_4, HCO_3, NO_3, NH_3, Br, B dissolved ions. Overall, we have collected and analyzed nearly 500 water samples as part of the MERC project.
4. Isotopic analysis of dissolved salts (strontium, boron, sulfur) and water molecule (Oxygen and hydrogen).
5. Conducting mass-balance calculations in several segments along the river that included river in-and outflows, all identified inflows, and pumping data for the particulate dates of conducting the mass-balance measurements.
6. Interpretation of the discharge and chemical results.

Previous studies and available information on the geology, hydrology, hydrology and hydrochemistry were collected and analyzed, in accordance to their relevance to the present study. The search for previous data information revealed scatter data that covers only partial information (both in time and space) on the water quality of the river. No discharge previous information was useful due to several reasons. The few hydrometric stations ceased to operate in recent years. Old data is of less significance as the overall flow conditions and system operation have been drastically changed.

The establishment of a monitoring system depends on the availability and accessibility to the river and its sources. Our efforts to monitor the river was coupled with the activities of the Israeli Nature Reserve Authority (INRA), which already operates a basic sampling network along the river and have established working relations with the IDF. Soon we found out that military considerations become a vital component in searching sampling sites along the border with Jordan. Nevertheless, we were able to find 61 accessible sampling points along and in the vicinity of the Jordan River (Tables 1 and 2; Fig. 2). These locations represent different parts of the river with respect to natural and anthropogenic tributaries. In addition we began monitoring the chemical composition of the major surface inflow to the Jordan River.

In the West Bank, the Palestinian team selected 25 sampling sites that were chosen for collecting water samples in the study area. The samples were collected from Wadi Al-Malich in the north to Jericho in the south. The sampling sites cover the ground and surface water that flow to the Jordan River outside of the Jordan Valley. Table 2 shows the present and potential sampling sites of the Palestinian team.

Table 1: List of sampling sites along the Jordan River and western inflows. Site numbers are included in Fig. 1.

Site #	Site name	Site type	x (km)	y (km)
1	Alummot Dam	River	253	734.1
2	Beit Zera Bridge	River ,discharge	253.6	732.9
3	Yarmouk River	Eastern inflows	258.66	730.721
4	Dalhamiya Bridge	River ,discharge	253.8	728.58
5	Yarmouk	Input	254.09	727.9
6	Naharayim island	River	253.11	726.92
7	Nave Ur north (g78)	River *	253.49	722.65
8	Wadi Arab	Eastern inflows	255.33	722.46
9	Nave Ur south (g78)	River ,discharge	254.36	721.47
10	Hamadiya (56)	River ,discharge	253	716
11	Hamadiya (pump-north)	River *	253	715.6
12	Hamadiya (pump-south)	River	252.69	714.11
13	Ein Huga	Ground water	250.6	713.85
14	Ein Hasida	Ground water	251.2	713.8
15	Nahal Harod	Input	251.8	713.45
16	Wadi Ziglab	Eastern inflows	253.972	712.256
17	Nahal Nimrod (43)	Input	253.25	712
18	Maoz Hayim (g43)	River *	253.3	712
19	Jisr Shech Hussein	River ,discharge	254.4	711.5
20	Abu Thableh	Eastern inflows	255.185	707.4
21	Shifa (Kfar Rupin)	River ,discharge*	253.5	706.5
22	Zoor Tbdulla	Eastern inflows	254.549	705.706
23	E-Sakut	Ground water	251.7	696.8
24	Vadi El Malich	Input	251.4	696.1
25	Mahadat Abu Sachasil (23)	River ,discharge	253	690.2
26	Rajib Seebiya	Eastern inflows	254.039	685.241
27	Bassat Faleh	Eastern inflows	254.767	683.061
28	Bassat Faleh Wadi Botton	Eastern inflows	254.621	682.724
29	Bweib	Eastern inflows	254.298	681.452
30	Wadi Makman	Eastern inflows	254.58	678.945
31	Hawwaya	Eastern inflows	254.088	677.161
32	Mifshel	Eastern inflows	253.633	675.412
33	Zarqa River	Eastern inflows	252.16	668.42
34	Jisr Damiya	River ,discharge	250.53	667.81
35	Rasif	Eastern inflows	252.39	664.979
36	Abu Mayyala	Eastern inflows	251.594	663.906
37	Aqraa	Eastern inflows	251.202	663.905
38	Mallah Gdeida	Eastern inflows	253.438	663.845
39	wadi phara(tirza)	Input	248.935	661.975
40	Zor Dayir Shaman (tovlan)	River ,discharge	249.07	661.781
41	wadi ahmar	Ground water, Input	249	659.193
42	Gilgal (107)	River	249.9	657.6
43	Wadi Mallaha Karama	Eastern inflows	252.836	653.259
44	El Malacha	Ground water	250	651.2
45	Malacha & Uga (131)	Input	249.9	647.5
46	Allenby bridge	River ,discharge*	251.21	642.76
47	Kasr-al-Yahud	River ,discharge	251.8	638.6
48	Ein Hagla	Ground water	248.34	637.51
49	Kharar	Eastern inflows	253.164	637.445
50	Hisban Kafrain	Eastern inflows	253.256	635.427

Figure 2. Map of the sampling sites along the Jordan River.

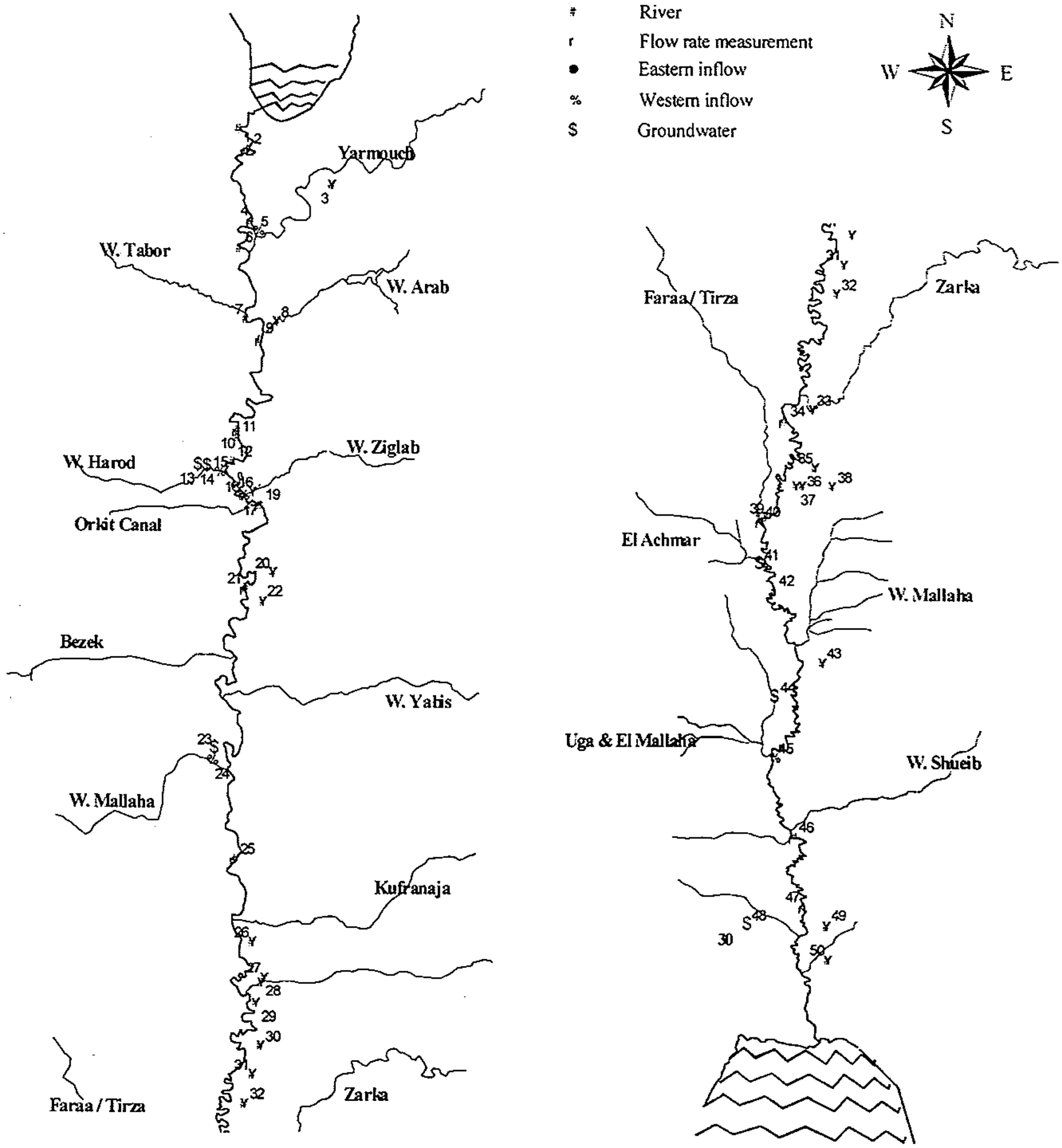


Table 2: List of sampling sites of the western flows and groundwater in the West Bank.

Springs	Location	Groundwater	Location	Surface water	Location
AC/242	Maleh	19-19/005A	Maleh/Bardalah	MA1	Maleh
AQ/030	Faria	19-18/002	Marj Naajeh	MA2	Maleh
AQ/039	Bathan	19-18/001	Marj Naajeh	FA3	Wadi Faria
AC/054*	Fasayel	18-18/019a	Wadi Faria	FA4	Wadi Faria
AS/022	Wadi Quilt	19-17/044	Wadi Faria		
		19-17/046	Wadi Faria	Q1*	Wadi Quilt
		19-17/033	Jeftlic	Q2*	Wadi Quilt
Ein Hajla*	Jericho	19-16/005	Wadi Faria	MM1*	Wadi Maleha
		18-10/002	Fasayel		
		19-15/001	Uja		
		19-15/023	Uja	MM2*	Wadi Maleha

* Potential sampling sites during winter and spring months.

2.2. Methodology and analytical techniques

2.2.1.Discharge Measurements

1. Velocity and flow rate

Velocity measurements were obtained using a portable acoustic Doppler velocimeter (3D Argonaut-ADV, Sontek) in the river and a portable electromagnetic current meter (Marsh- McBirney 2000 Flo-Mate) in the tributaries. Flow-rate was then obtained by integrating the measured velocity across the cross sectional area of the river and tributaries.

The 3D Argonaut-ADV geometry defines a measurement volume of 0.25 cc at a fixed distance of 10 cm from the transmitter. Using integrated compass and tilt sensors the velocity vector was given in earth coordinates. Each sample represents an average of 100 samples (taken at 10 Hz for 2 seconds each), and includes the velocity, the depth of the sampling volume, distance to boundary, and standard deviations of all parameters. The standard deviation of the velocity consists real variations and Doppler noise. The noise level of the instrument affects the velocity by 1% of the measured value. In general, turbulent and other variations are larger than the instrument noise. A high concentration of suspended particulate matter is typical in most of the Lower Jordan River sections. As a result, the signal strength was higher than the noise level by about 35 dB.

The ADV was mounted on a vertical pole held by a construction bridge and floats (Fig. 3.1). The vertical pole is capable of moving up and down using a step motor and a control cable. Magnesium horizontal poles (not shown in the figure), 3m long, were inter-connected by special connectors and extra floats to allow lateral motion. The Mg was chosen due to its high strength and low weight properties. Power supply for the laptop computer, the step motor and the 3D Argonaut-ADV was provided using a DC to AC Power Inverter (Cherokee), a field 12v battery and a recharging device. A serial communication and a portable computer were used for instrument control and data recording. By cruising the floating construction across the river, both water velocity and river bed profiles were obtained.

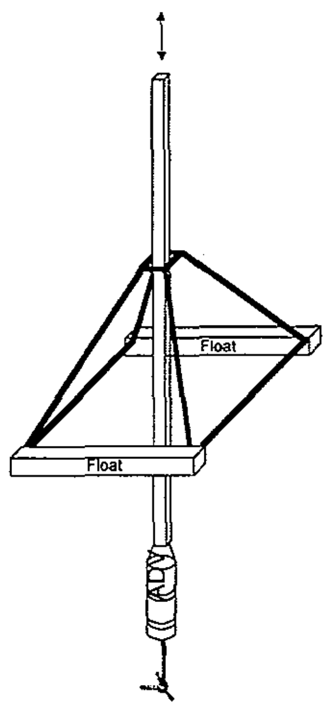


Fig. 3.1. The ADV and its floating traverse construction

Velocity in the western tributaries was measured with a Marsh McBirney electromagnetic current meter (Flo-Mate, model 2000), using a spherical sensor head of 0.013 m in diameter. Velocity measurements were taken at a few locations across the stream. A cross-section profile was drawn, its area was calculated, and the velocity was integrated to provide a flow-rate result with an error of less than 10%. A comparison between an ADV system and the electromagnetic current meter (ECM) has been undertaken by Lane et al. (1998) showing reasonable agreement. A good agreement between the ADV and the ECM was found during a comparison test inside the Jordan River tributaries.

Velocity measurements were obtained in several cross-sections along the north part of the river, its western and eastern tributaries. During the measurements, water level along the river was monitored and pumping discharge volumes were reported by the relevant stations. Vertical velocities profiles were interpolated and extrapolated using a power law model, $u = \alpha z^{m}$, where u is the velocity component normal to river cross-section, z is the height from the river bed, and α and m are constants. Following Gonzalez et al. (1996), m is 1/6 where α was computed by a least-squares curve fitting. The distribution of measurement locations, the results of a river bottom profiling, and q comparison between the fitted 1/6 power law and measured velocity (Dec. 2000) in three representing profiles are shown in Figs. 3.2 & 3.3. The velocity integration procedure is defined by,

$$Q = \int_{z=0}^{z=H} \int_{y=f_1(z)}^{y=f_2(z)} \alpha z^m \, dy dz \tag{1}$$

where $f_1(z)$ and $f_2(z)$ represent the two half shape functions describing the bed profile.

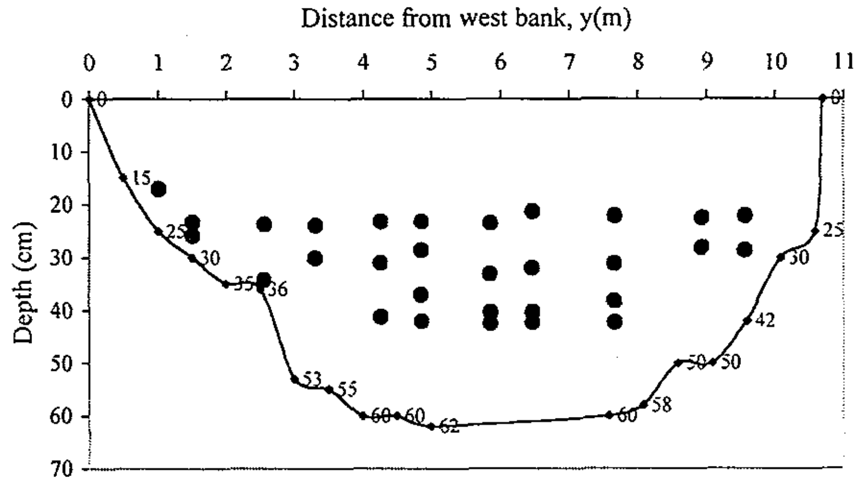


Fig. 3.2 The river bed profile and location of velocity measurements at Dalhamiya Bridge (not to scale)

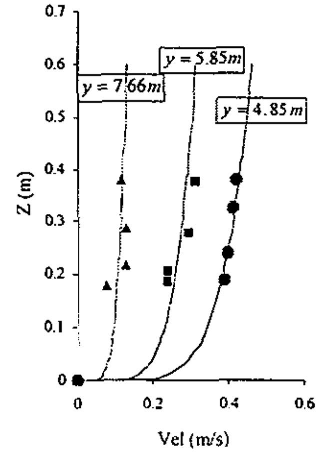


Fig. 3.3 Vertical velocity profiles

2. Mass balance and sensitivity analysis

Instantaneous mass balance calculations for water and conservative solutes were obtained by assuming a steady state condition. The water mass balance is,

$$\sum_{i=1}^{N} Q_i \tag{2}$$

where Q_i is the flow rate at an inlet i. The conservative solutes mass balance equations are,

$$\sum_{i=1}^{N} Q_i C_i^j \tag{3}$$

where C_i^j is the concentration of a specie j at an inlet i. When only one inlet is unknown, Eq. 2 is solved to provide the unknown discharge, and Eqs. 3 are used to calculate the unknown chemistry. When more than one variable is unknown a combination of Eq. 2 and Eqs. 3 is needed.

Further, a matrix representation of Eqs. 2 and 3 was used to examine the sensitivity of the flow rate measurements and the mass balance calculations. Combining Eqs. 2 and 3 yields a matrix form as follows,

$$\begin{bmatrix} \Re \\ C \end{bmatrix} [Q] Q_N^{-1} = \begin{bmatrix} 1 \\ C_N \end{bmatrix} \tag{4}$$

where $\Re$ is a vector containing 'ones', C is a matrix representing the concentration of species (rows) at the sampling sites (columns), Q is a vector representing the flow rate at each site excluding the outlet, Q_N is the outlet flow rate, and C_N is the a vector containing the species concentration at the outlet. A sensitivity analysis is obtained by comparing the measured flow rate with solutions of Eq. d using pseudo perturbations in the C matrix.

2.2.2. Geochemistry

Water samples were measured for major chemical constituents (that include, Ca, Mg, K, Na, Cl, SO_4, HCO_3, NO_3, NH_3, Br, B) at the laboratories of the Israel Geological Survey and University of Amman. Strontium was separated by ion-exchange columns at the Water laboratory of Ben-Gurion University and the isotopic composition was measured using a MAT-261 mass spectrometer at the laboratory of US Geological Survey, Menlo Park, California. Boron isotopes were measured by negative thermal ionization mass spectrometry (Vengosh et al., 1989; 1999) using a MAT-261 at US Geological Survey, Menlo Park. Oxygen isotope ratio measurements were made on a VG SIRA-II mass spectrometer at the Geological Survey of Israel. Results for oxygen and boron isotopes are given in per mil values with respect to SMOW (Craig, 1961) and NBS-SRM 951standards, respectively. Sulphate was separated at the laboratories of the Israel Geological Survey and isotopic measurement were carried out at the British Geological Survey, Nottingham, UK. Analytical reproducibility of duplicates and replicate analyses are 0.1‰, 1‰, 0.5‰, and 0.025‰ for O, B, S, and Sr isotopes, respectively.

3. Scientific Results

The results reported here are accumulated data for the years 2000 and 2001. It should be noted that the hydrological years of 2000-2001 followed three consecutive draught years and hence the results represent base flow with minimal contribution of runoff. Nevertheless, this is a unique opportunity to test the river flow and conditions in draught conditions thus future predictions for "the worse case scenarios" would became more reliable.

3.1. Flow rate measurements and mass balance calculation

3.1.1. River Flow-rate

River flow-rate was obtained between February 2001 and August 2001. The results, which were obtained in Dalhamia, Neve-Ur and Hamadia in the north (see Fig. 4) and in Zarzir and Tovlan in the south, represent the flow during the winter and summer of 2001. Both winters 1999/2000 and 2000/2001 suffered from low level of precipitation. The limited precipitation conditions lead to at least three drying events (in May 1999 and May 2000 at Shifaa, and in July 2001 at Neve-Ur). The measured flow rate in the river is summarized in Table 3. Previous estimations of the river flow-rate (Al-Weshah 2000 and Tahal 2000) are higher than the results of the current measurements.

Table 3 Measured flow rate in the river section during Feb – Aug 2001

Tahal (2000)		**Aug 2001**	**June 2001**	**April 2001**	**Mar 2001**	**Feb 2001**	**Date**
Draught Year	Average Year						**Site**
954	954	676	659	757	921	883	**Dahlamia**
		808	1087	862	695	839	**Neve Ur**
1135	2040	480	1073	819	1007	1155	**Hamadia**
		302	1198	-	-	-	**Zarzir**
3399*	4855*	373	1665	-	-	-	**Tovlan**

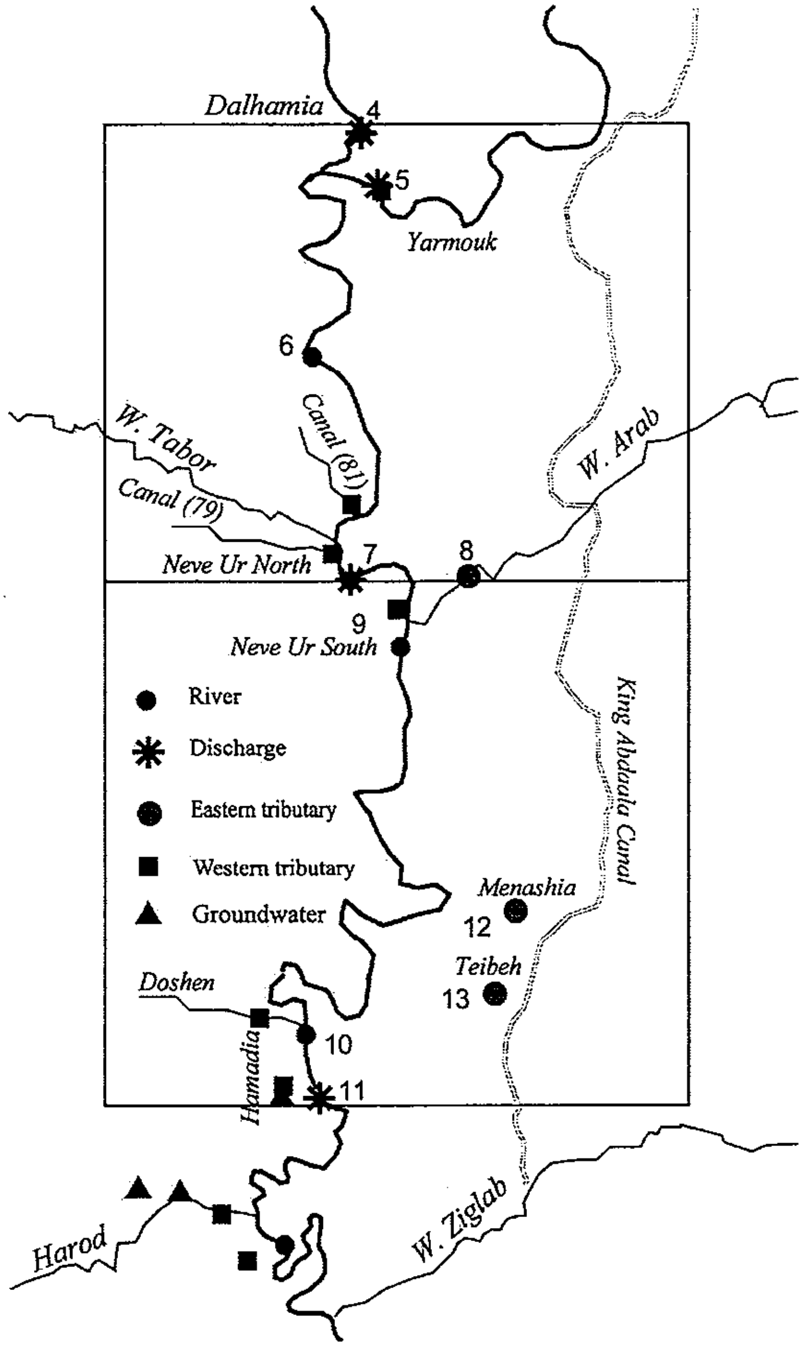


Fig 4. A detailed map of the Dalhamia Hamadiya region

3.1.2 Mass Balance

Water mass balance requires a reliable inventory of all inputs and outputs. Such an inventory must include all flow rates flowing in and out from the river section at the same time. In addition, storage must be monitored by means of water level along the river at as many locations as possible.

Accessibility limitations did not allow such an ideal situation. However, pumping rates were provided by the water personal. Flow rate was measured in the river and its tributaries with in a day or two. Water level was continuously monitored in only limited number of sites and during some of the measurements. The mass balance calculated for the Neve-Ur Hamadia section is shown in Table 4.

Table 4 Mass balance calculations in the Neve-Ur Hamadia section.

#	Site name	February 2001	March 2001	April 2001	June 2001	Aug 2001
1	Neve-ur	839	695	862	1087	808
1	Neve-ur pumps (78)	-160	-233	-231	-243	-276
2	Wadi el arab	160	165	165	85	45
3	Irrigation (76)	0	0	49	50	0
4	Neveur pumps (74)	-80	-80	-49	-104	-97
5	Irrigation (74)	0	0	0	270	0
6	Menashia	18	30	30	0	0
7	Teibeh	3	0	0	30	9
8	Doshen pumps (56)	-244	0	-231	-252	-267
9	Doshen canal (56)	87	12	13	13	0
10	Zor pumps (55g)	-167	-125	-118	0	0
10	Hamadia	-1155	-1007	-819	-1073	-480
-	Evapotranspiration	-16	-24	-24	-24	-32
-	**Calculated inflow**	**716**	**568**	**353**	**163**	**290**

Table 4 shows that the flow rate of the unknown input is of the same order of magnitude as the river discharge. The largest value was found in February 2001. The unknown flow-rate was reduced to a minimum in June and then increased again in August to a level of 290 ℓ/s. The results in Table 4 were implemented in Eq. 2 and the unknown chemistry was calculated. The results obtained for Feb. 2001 are shown in Table 5.

Table C The chemistry of the unknown component as was calculated for the Neve-Ur Hamadia section in February 2001.

Site	Discharge (l/sec)	Ca	Mg	Na	K	Cl	SO4
Neveur	839	324	148	882	45	1890	372
Neveur north pumps	-160	324	148	882	45	1890	372
w. el arab	160	134	93	262	45	300	510
Neveur south pumps	-80	296	144	760	41	1599	380
Menashia	18	244	220	412	47	515	1330
Teibeh	3	244	220	412	47	515	1330
Doshen pumps	-244	270	160	729	39	1493	460
Doshen canal	87	300	175	850	44	1800	510
Zor pumps	-167	270	160	729	39	1493	460
Hamadia	-1155	270	160	729	39	1493	460
Evapotranspiration	-16						
Calculated unknown	716	**243**	**177**	**670**	**30**	**1352**	**481**

In general the chloride concentration is low and the sulfate concentration is high. As shown in Table 6 this result repeats it self through out the measurements.

Table 6 Chloride and sulfate of the unknown component in the Neve-Ur Hamadia section

	Date	Discharge	Cl	SO4
	Units	**L/sec**	**mg/L**	**mg/L**
Neve-ur	**Feb**		*1890*	*372*
Unknown	**Feb**	716	1352	481
Neve-ur	**March**		2040	410
Unknown	**March**	568	1834	533
Neve-ur	**April**		2120	370
Unknown	**April**	353	1482	637
Neve-ur	**August**		2240	300
Unknown	**August**	290	1048	436

The water sources that mix to form the unknown inflow can be traced by examining ion ratios of relevant chemical components.

3.2. Geochemistry

The chemical and isotope data of the Jordan River, between Alumot Dam in the north and the Dead Sea in the south, reveal three geographically distinct zones (Figs. 6 and 7): the upper (the first 20 km), central (20-65 km), and lower (below 70 km) sections. Table 1 summarizes the main geochemical characteristics of the Jordan River and selected identified inflows.

Table 7: Summary of the chemical variations of the Jordan River and selected inflows

Site	Cl (mg/l)	SO_4 (mg/l)	Na/Cl [1]	SO_4/Cl [1]	Mg/Cl [1]	B/Cl [2]	$^{87}Sr/^{86}Sr$	$\delta^{11}B$ [3]	$\delta^{34}S$ [11]
Upper Jordan									
Initial river [4]	2100-2500	170-185	0.66-0.70	0.03	0.07	0.8	0.70775	30	20
River 20 km [4]	1470-1600	440-530	0.75-0.88	0.10-0.13	0.15	1.4-2.0	0.70766	30	4-5
Western inflows									
Harod inflow [5]	1730-1960	200	0.71-0.78	0.04	0.12	0.7	0.70782	39.5	
Nimrod inflow [6]	1900	240	0.64	0.05	0.18	0.5	0.70791	38	
Chanal 17 [6]	1370	180	0.62	0.05	0.19	0.8	0.70785	36	
Hogla springs [6]	1560	230	0.65	0.05	0.14	0.7	0.70783	43	
Eastern inflows									
Yarmouk River [4]	840-1200	580-850	0.91-0.96	0.23-0.26	0.27	5.3-6.0	0.70719	36.5	-2
Wadi Arab [7]	174	100	0.85	0.21	0.29	-	-		-3.9
Wadi Ziqlag [7]	108	80	1.00	0.26	0.46	-	-		
Central Jordan									
River 27 km [4]	1300-1670	370-420	0.76-0.87	0.08-0.11	0.15-0.18	1.4-1,6	0.70771	31.5-33	5.9
River 44 km [5]	1300-1570	370-410	0.74-0.76	0.10-0.11	0.17-0.19	1.5-2.0	0.70785	36.7	1.9
Western inflows									
Wadi Al-Malich [8]	1330-1500	330-360	0.69-0.73	0.08-0.10	0.10-0.13	1.5-2.2	0.70776	38	22.2
Sukot spring [9]	430-450	175	0.80-0.86	0.15	0.29	2.0-2.6	0.70798	47.5	
Eastern inflows									
Abu Thableh [7]	330	160	0.95	0.18	0.25	-	-		
Zoor Tbdulla [7]	1500	470	0.80	0.11	0.14	-	-		
Southern Jordan									
River 66 km [4]	1430-1680	500-715	0.75-0.93	0.11-0.16	0.7-0.23	1.8-3.1	0.70815-0.70829	31	5.6-7.2
River 76 km [5]	1600-2300	670-970	0.77-0.79	0.15	0.18-0.19	2.1-2.7	0.70814	33	7.1
River 91 km [4]	1650-2400	680-1030	0.73-0.80	0.14-0.17	0.16-0.19	2.4-3.0	0.70809-0.70820	31	5.0-5.8
River 96 km [4]	1740-2200	560-900	0.76-0.80	0.11-0.17	0.17-0.19	2.3-2.8	0.70813	31	5.6-6.4
River 100 km [10]	5370	1650	0.66	0.11	0.19	1.7			

Western inflows									
Al-Ahemar [9]	38,000	1800	0.57	0.02	0.15	0.4	0.70796	41.7	4.3
Uja-Meleha [5]	2250-2550	890-1020	0.68-0.70	0.15	0.21	2.8-3.6	0.70797	41.7	-17
Tirtza well [7]	14,200	680	0.67	0.02	0.11	2.3	-	-	
Eastern inflows									
Wadi Makman [7]	820	1340	1.0	0.60	0.45	5.1	0.70804	26.2	-
Mallah Gdeida [7]	960	1300	0.81	0.50	0.38	3.9-4.7	0.70807	28.5	
Zarqa River [7]	1360	1120	0.80	0.30	0.23	4.0-5.5	0.70870	24.5	10.0
Rasif [7]	4830	3040	0.87	0.23	0.23	3.6-5.5	0.70836	33.7	
Aqraa [7]	30,500	2330	0.56	0.03	0.22	1.5	0.70802	48.2	10.2

Legend for Table 7:

1. Molar ratios.
2. ($x10^{-3}$).
3. Values reported in permil (‰), $\delta^{11}B= [\{(^{11}B/^{10}B)_{sample}/(^{11}B/^{10}B)_{NBS\ 951}\} - 1]\ x1000$.
4. Values represent sampling between September 1999 to September 2000.
5. Sampling on March, May and August 2000.
6. Sampling on May 2000.
7. Sampling on September 2000.
8. Sampling on September 1999, March and May 2000.
9. March and May 2000.
10. August 2001.
11. Values reported in permil (‰), $\delta^{34}S= [\{(^{34}S/^{32}S)_{sample}/(^{34}S/^{32}S)_{STD}\} - 1]\ x1000$.

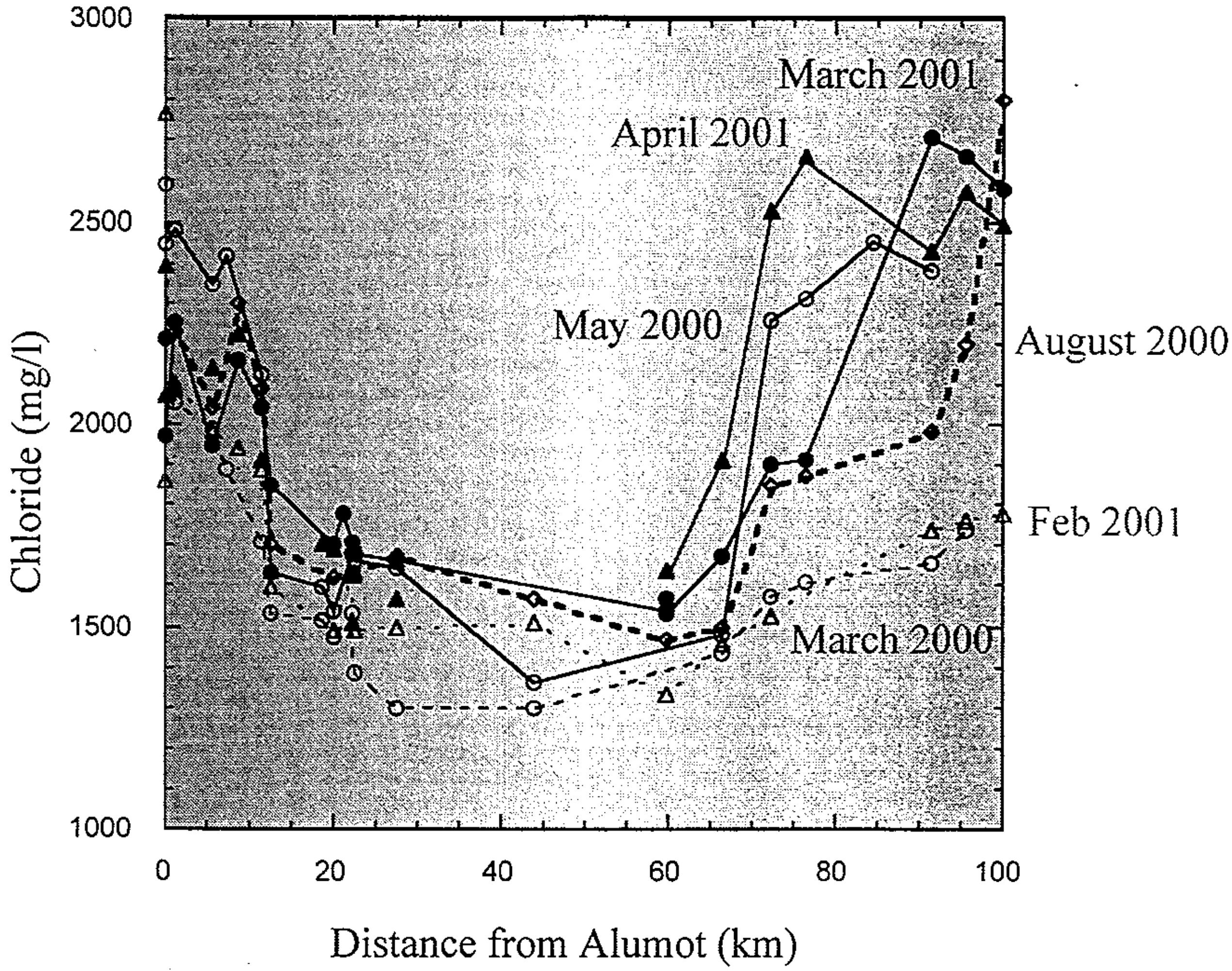


Figure 6. Chloride variations along the Jordan River. Note the three major salinity zones along the flow of the Jordan River. Distance in km is referenced to y coordinate rather than actual river length from its beginning at Alumot Dam.

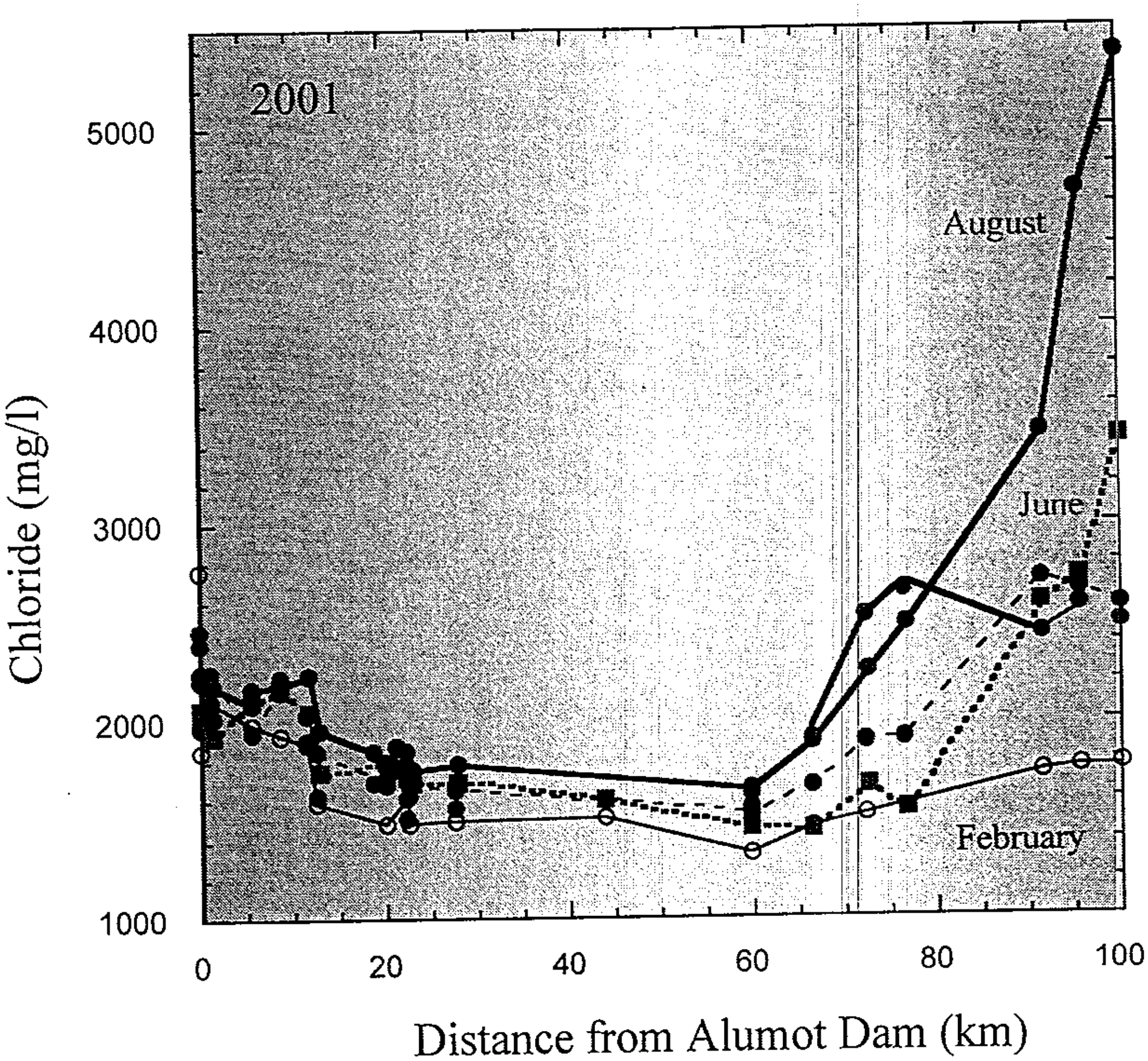


Figure 7. Chloride variations along the Jordan River, including sampling of August 2001. Distance in km is referenced to y coordinate rather than actual river length from its beginning at Alumot Dam.

3.2.1 The upper northern zone

The first section (a length of 20 km downstream from the Sea of Galilee) is characterized by a decrease in Cl^- and Na^+ concentration and an increase in Mg^{2+}, SO_4^{2-}, and B concentration (Figs 6, 7, and 8). The chemical change is accompanied by changes in the $\delta^{18}O_{water}$, $^{87}Sr/^{86}Sr$, $\delta^{34}S_{sulfate}$ and $\delta^{15}N_{nitrate}$ values (Table 1). Along the upper flow of the Jordan River the $^{87}Sr/^{86}Sr$, $\delta^{34}S$, and $\delta^{15}N$, and $\delta^{18}O$ values changed from 0.70775 to 0.70763, 20‰ to 5‰, 2‰ to 20‰, and –4‰ to –2.5‰, respectively. These variations include both a gradual modification along the flow path and abrupt changes due to tributary inflows. The gradual changes and the linear relationships between the Cl^- and other dissolved salts (e.g., sulfate; Fig. 8) are caused by a mixing of the effluent + Saline Carrier water flowing in the River with a different water having a distinct chemistry. The western saline inflows are characterized by Ca-chloride composition with low Na/Cl and SO_4/Cl ratios and relatively high $^{87}Sr/^{87}Sr$ (0.7078 to 0.7091), and $\delta^{34}S$ (20‰) values. This chemical composition is significantly different from that of the down-flow Jordan River. In addition, the eastern inflows have considerably lower salt content that cannot explain the change in the chemical composition of the Jordan River. Since the tributary inflows alone cannot account for all the chemical modifications along the flow path, we argue that an additional "unknown" source discharges into the river. This source must be characterized and be included in future management strategies of the river system.

The Yarmouk River constitutes a unique hydrological configuration from which the unknown source of Jordan River water can be identified. The Yarmouk is dammed and its water is diverted. About 130 MCM of Yarmouk water is annually diverted through King Abdalla Canal for use in Jordan. As part of the Peace Treaty with Israel 25 MCM is allocated for Israel in addition to 20 MCM that is pumped in the winter, stored in the Sea of Galilee, and transferred back to Jordan in the summer. Prior to the peace treaty, Israel used about 70 MCM for mostly irrigation in the upper Jordan valley.

Although no tributary inflow exists beyond the dam, the nearly zero flow-rate downstream from the dam increases significantly towards its confluence point with the Jordan River. While the salinity upstream from the dam is very low (140 mg Cl/l), the salinity of the downstream water is high (>1000 mg Cl/l). The source of this water can be partly traced to irrigation return flows that discharges into the Yarmouk. It should be noted that a pumping station at the mouth of the saline Yarmouk River, upstream from its confluence point with the Jordan River, pumps most of the surface Yarmouk water for fishery and irrigation uses. Hence the direct inflow from the Yarmouk River, is minimal and therefore should have little impact on the water chemistry and flow rate of the Jordan River. Nevertheless, our data show that the geochemical signature of the saline Yarmouk River is consistent with the chemical and isotopic modifications observed along the Jordan River, both upstream and downstream from the Yarmouk River (Fig. 9). Consequently, the saline Yarmouk water may be considered as a direct measure of the unknown source that affects the Jordan River.

A detailed mass-balance calculation over a segment of the Jordan River between Neve-Ur – Hamadia segment and Hamadia was conducted by using flow-rate measurements and chemical analysis. The detailed water and solute mass-balance was preformed along two river segments in the north and one segment in the south (Fig. 1). When including all known inputs and pumping rates, and assuming a pseudo steady state condition, an unknown input was discovered with a significant flow-rate and a characteristic chemistry. Our mass-balance calculation enables estimation of the flow-rate and chemical composition of the unknown water source, showing that its maximum discharge in this segment (Fig. 1) comprises 70% of the total river discharge in the winter (February, 2001). It decreased to about 15% in the late spring and increased again to 45% in the summer (August 2001). The chemical and isotopic variations enable to constrain the expected chemical composition of the groundwater inflow: high NO_3^- and SO_4^{2-} concentrations, low $\delta^{34}S$ and $^{87}Sr/^{86}Sr$, and high $\delta^{18}O$ and $\delta^{15}N$ in nitrate (Fig. xx). This suggests that the groundwater is impacted by anthropogenic contaminants via both agricultural return flows and waste waters. In sum, the saline initial source water of the Jordan River that is composed of artificial inlet of sewage and saline waters is modified along the upper 20 km into less-saline water with high contaminants (e.g., NO_3^-, SO_4^{2-}) level due to gradual groundwater discharge (Table 1).

As mentioned above, our chemical data may be biased as our samples represent base flow in the second of three consecutive draught years. We expect that flood events would drastically change the hydrological balance of the river. Nevertheless, the chemical composition of the river, which is controlled mainly by the saline sources, would be less affected by low saline floodwaters.

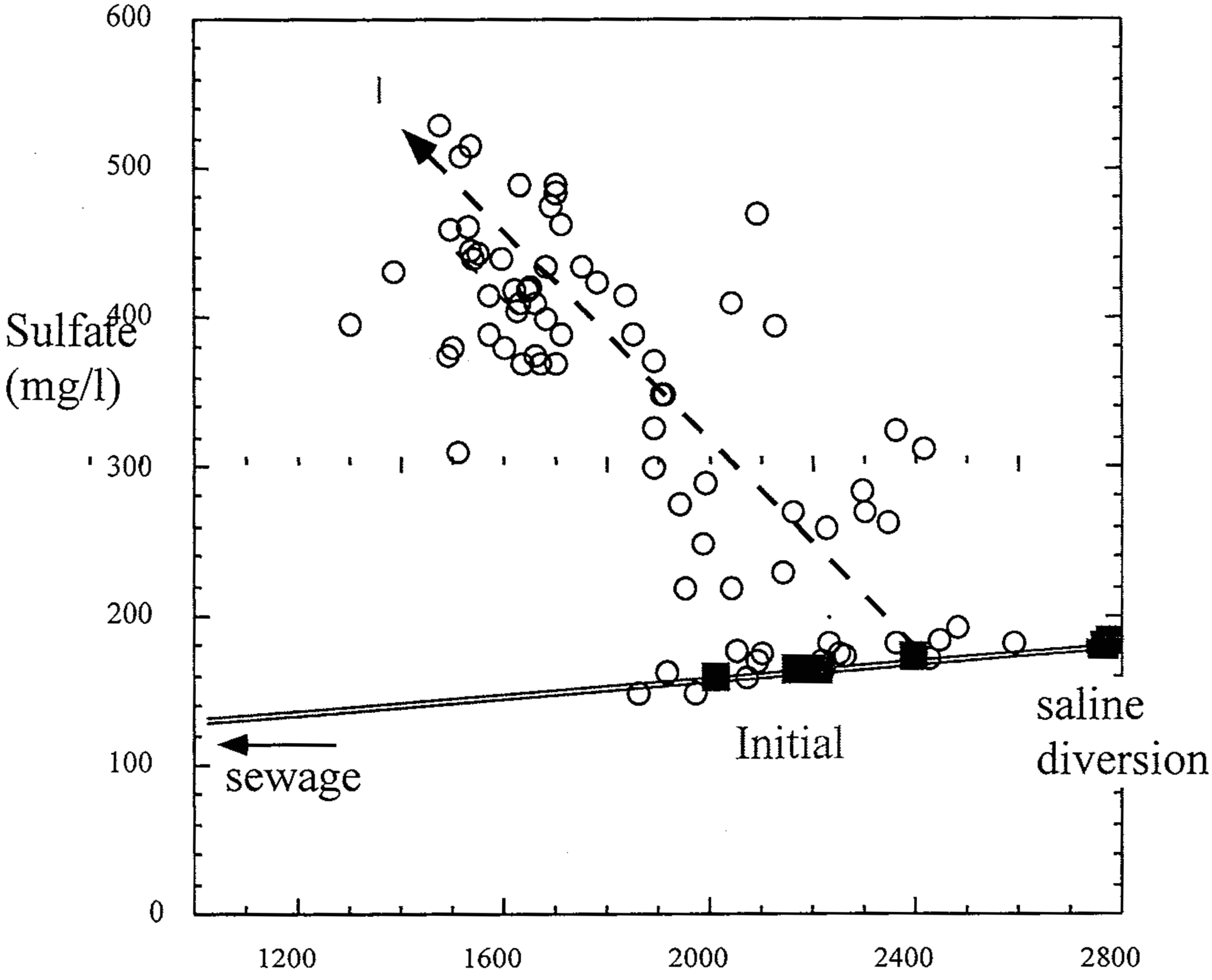


Figure 8. Chloride versus sulfate concentrations of the Jordan River (circles), and the initial base flow, composed of a blend of saline water (saline diversion) and sewage effluents. The dashed arrow represents the flow direction of the Jordan River.

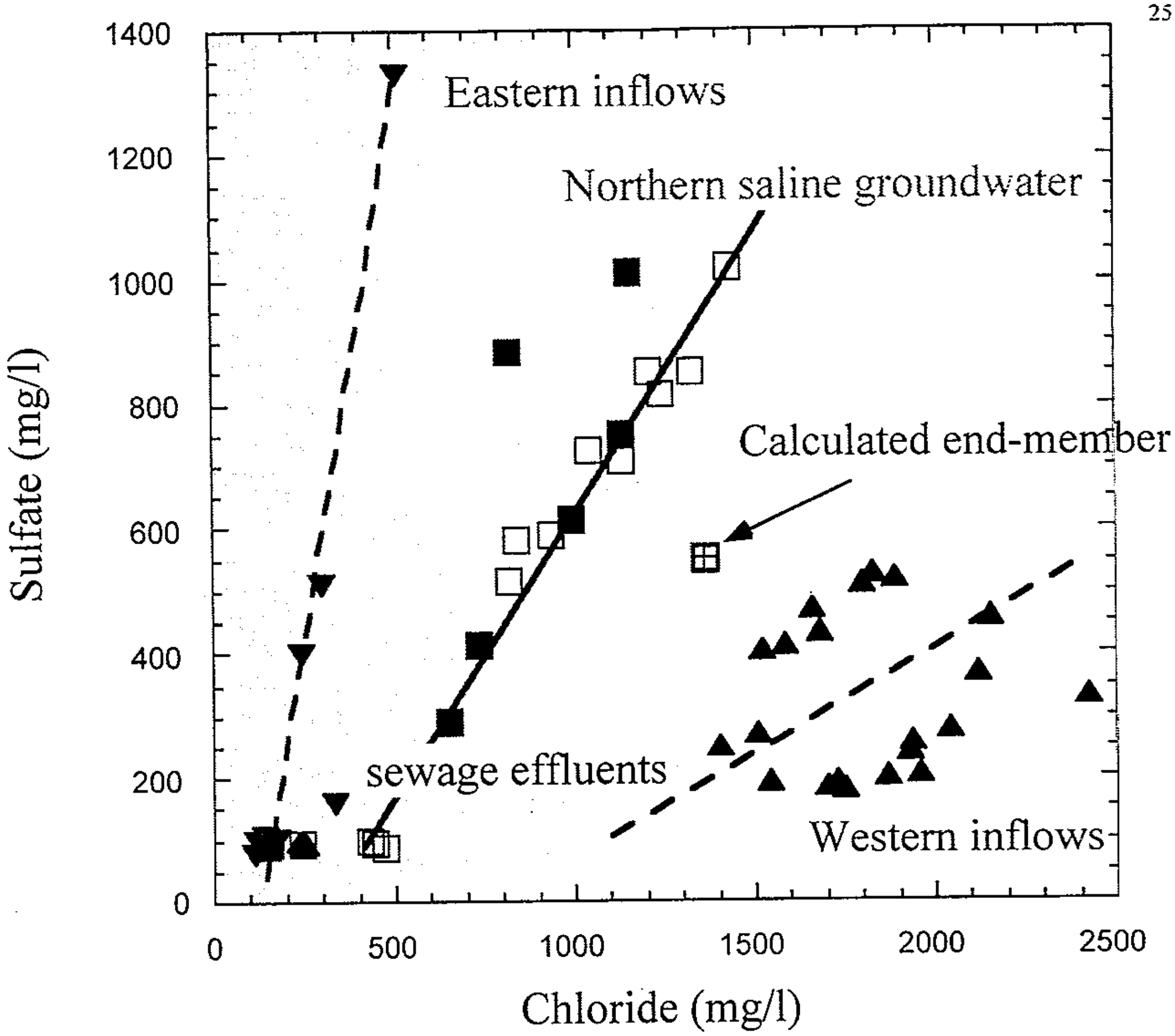


Figure 9. Chloride versus sulfate concentrations of eastern inflows (red triangles), local shallow groundwater(open squares), saline Yarmouk River (Closed squares), and western saline inflows (blue triangles). Note the similarity between shallow groundwater and the saline Yarmouk River, implying a common source.

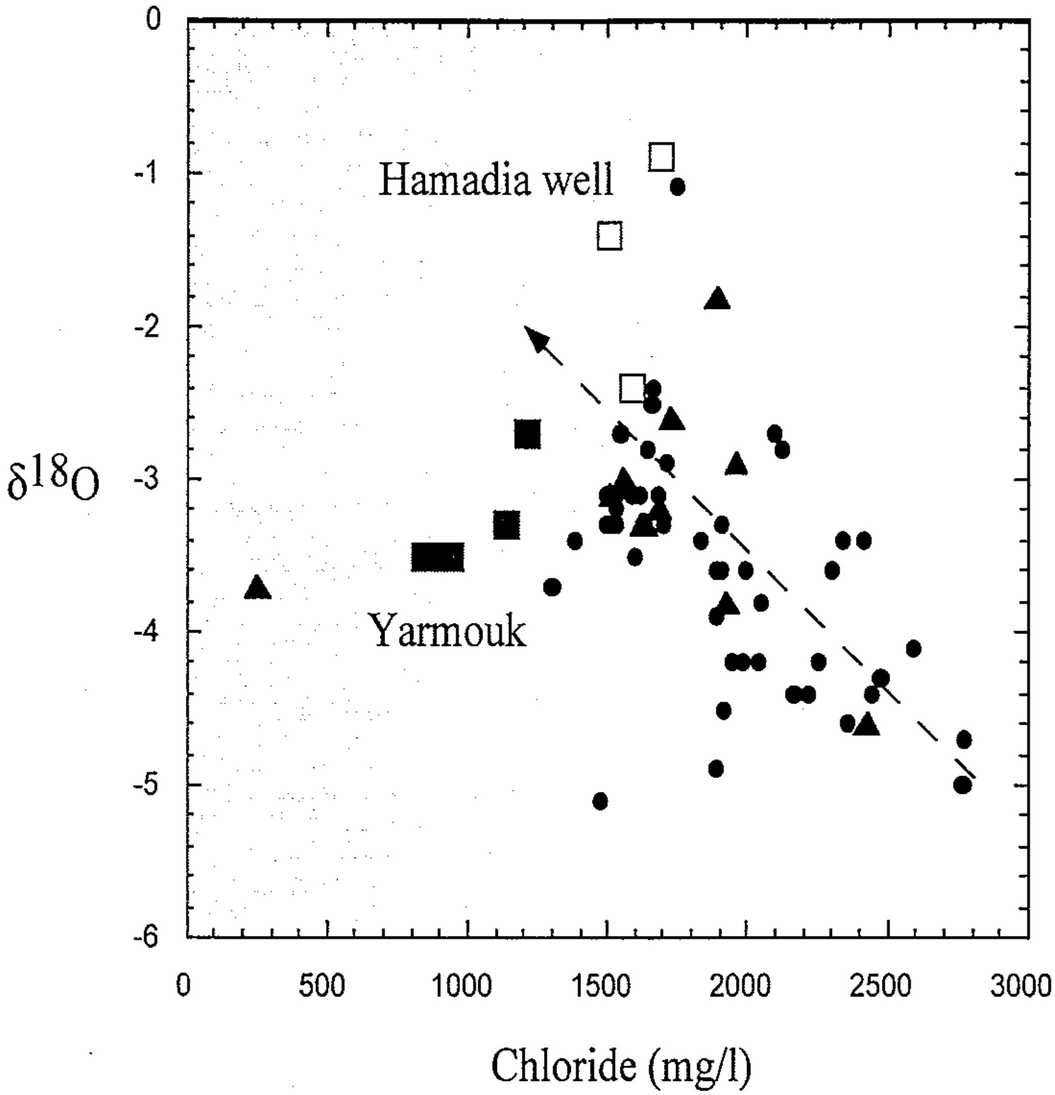


Figure 10. Chloride vs. $\delta^{18}O$ of the Jordan River (closed circles), western inflows (blue triangles) and the saline Yarmouk River (closed squares). Dash arrow represents flow direction of the Jordan River. Note the gradual $\delta^{18}O$ increase with deceasing salinity.

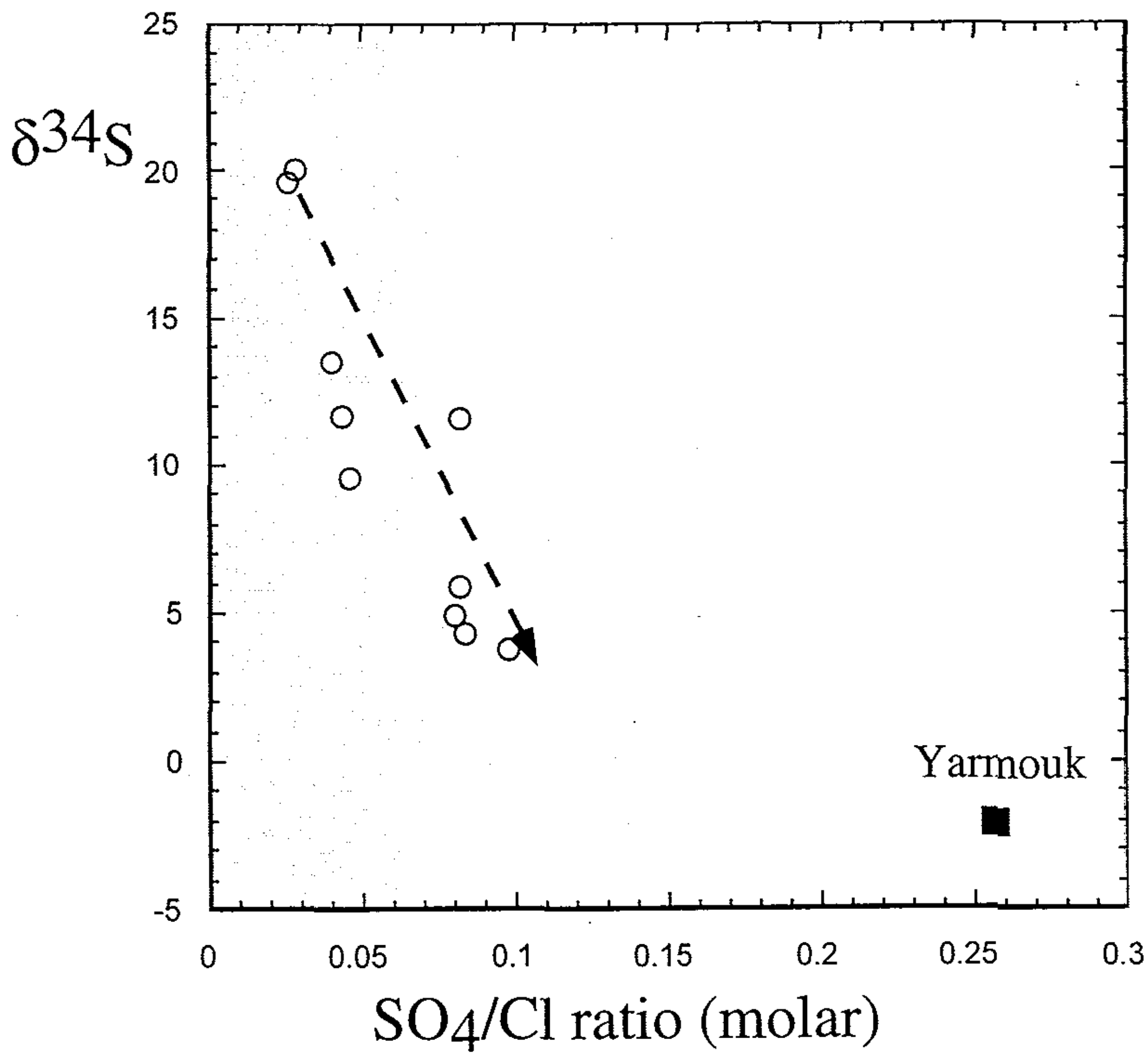


Figure 11. Sulfate to chloride ratio versus $\delta^{34}S$ values of the northern Jordan River (open circles) and saline Yarmouk River (closed squares). Arrow represents flow direction of the Jordan river.

3.2.2. The central zone

The central zone of the Jordan River show relative of low salinity level relative to the upper and lower sections (Fig. 6) . Our results show that the geographical location of this low salinity changes with time. During winter (March, May) the low salinity occurs between 20 to 45 km, whereas in summer (August, September) the low salinity section stretches between 20 to 65 km. This phenomenon is consistent with the distribution of Cl, Mg, Ca, and Na. However, The SO_4 variations show only low levels along the 20 to 45 km interval and are not sensitive to these seasonal variations.

The chemical (e.g., SO_4/Cl, Na/Cl) and isotopic compositions of the central Jordan River is significantly different from that of the saline springs and western inflows (e.g., Hammam Al-Malich originated in the West Bank, Hogla springs; Table 1). For example the saline springs of Hamme Al Malich has a high $\delta^{34}S$ signal (22‰) relative to the river (1-6‰), thus excluding these inflows as a major source. In contrast, the and eastern inflows (Abu Thableh, Zoor Tbdulla; Table 7) have chemical compositions (e.g., high SO_4/Cl ratio) that are similar to that of the Jordan River (Table 7).

3.2.3. The southern zone

The southern section of the Jordan River is characterized by a salinity increase. We observed seasonal changes in the locations and composition of this salinity increase. During the spring, a high salinity peak is identified between 60 and 75 km downstream from the river source, whereas during the summer months the salinity is gradually increasing with flow, reaching a peak at the southern sampling point (Fig. 7). The two salinity events also differ in chemical composition: the spring salinity event is characterized by relatively higher SO_4/Cl and Na/Cl, and lower Br/Cl ratios (Fig. 13). Linear relationships between Cl^- and other constituents (Fig. 12) and gradual decrease of $\delta^{18}O_{water}$ values suggest that mixing processes control the salinity variations of the southern Jordan River. However, these mixing processes are different from those in the north. Three types of saline water are identified in the southern Jordan Valley:

(1) The Zarka River is a base flow of saline springs (1700 mgCl/L) emerge below King Talal dam, characterized by high Na/Cl, SO_4/Cl, low $\delta^{11}B$ (25‰), and high $^{87}Sr/^{86}Sr$ ratios (0.7087) and $\delta^{34}S$ (10‰);

(2) Saline groundwater that flows within the Lisan Formation with salinity of up to 6,000 mg/l and typically high SO_4/Cl, Na/Cl, and low $\delta^{11}B$ (30‰) and $^{87}Sr/^{86}Sr$ (0.70805) values;

(3) Brines (up to 60,000 mgCl/l) with typically low SO_4/Cl, Na/Cl, and high $\delta^{11}B$ values (>40‰), and $^{87}Sr/^{86}Sr$ ~0.70805.

Our mass-balance calculations show that none of these three water sources can be the sole contributor to account for the changes in the chemical composition of the river. Only a blend of 80 to 90% of saline groundwater and 10 to 20% of brine can explain the chemical modifications observed. The estimated and measured surface flow of these sources do not comprise with these estimate, suggesting that the saline water and the brine discharge as groundwater into the River along its flow path. The $^{87}Sr/^{86}Sr$ and $\delta^{11}B$ values found in both the saline groundwater and the river (Fig. 1) mimic those of the Lisan Formation (Stein et al., 1997). . As mentioned above, the

Lisan Formation is the local geological unit in which local groundwater and Jordan River flow. In contrast, The $\delta^{34}S$ values of sulfate in the river (5-7‰) and associated groundwater (4-10‰) are different from that of the main gypsum layers in the Lisan Formation (14-28‰; Gavrieli et al., 1998). We postulate that the high salinity of local groundwater is derived from interactions with the reactive unflushed Lisan Formation type sediments, which are composed of aragonite, gypsum, and detrital components. The brines are derived from residual brines typical to the Rift Valley (Starinsky, 1974) entrapped within the Lisan Formation (Katz and Kolodny, 1997) or flow from underlying sources (Marie and Vengosh, 2001).

A large fraction of the irrigation water in the southern Jordan valley is derived from waste waters. In the eastern side about 30 to 40 MCM of treated waste water is annually blend with ~10-20 MCM of fresh water King Abdalla Canal and used for irrigation (Shatanawi and Fayyyad, 1996). In the western side an addition 30 MCM/year is irrigated. We suggest that massive irrigation increases groundwater level that triggers water-rock interaction, and consequently salinization of local groundwater and the river. Hence, the reactivity of the host sediments in an arid climate without significant flushing during the last 10 ka presents an additional source of salinity that masks the influence of the relative low saline irrigation water.

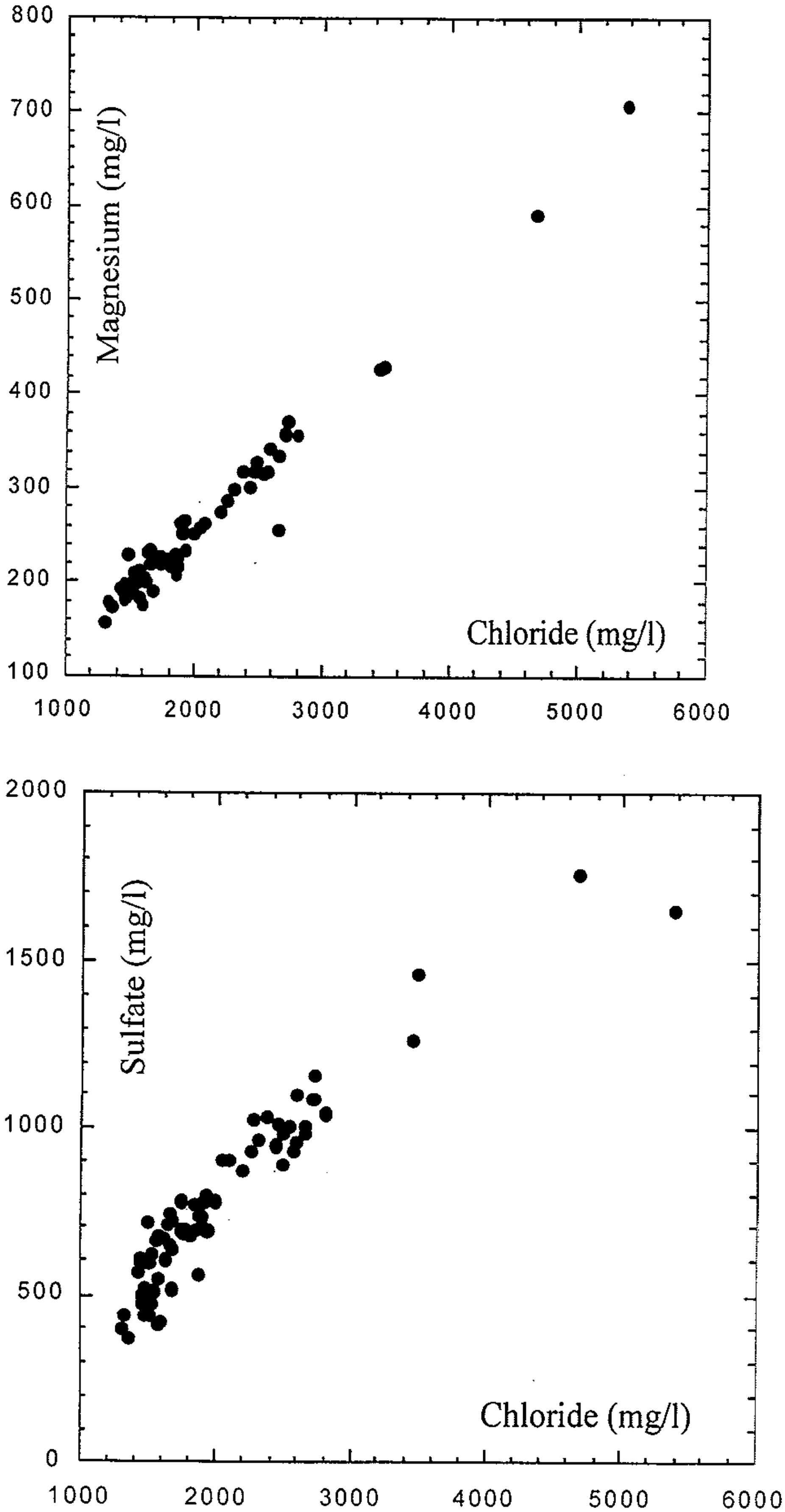


Figure 12: Chloride vs. sulfate and magnesim contents of the southern Jordan River.

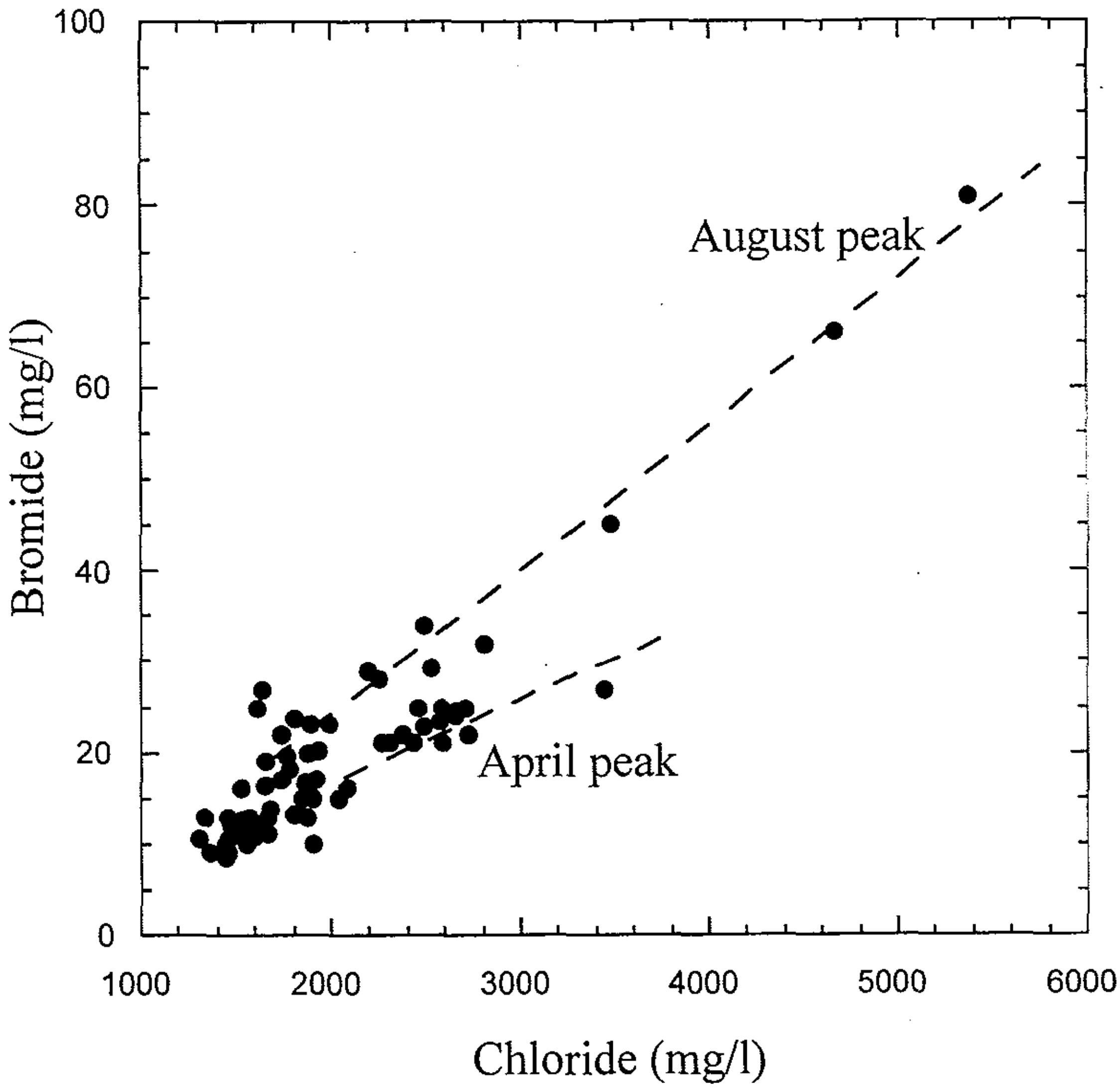


Figure 13: Chloride vs. bromide contents of the southern Jordan River. Note the differences in Br/Cl ratios between April peak of salinity and August salinization with a higher Br/Cl ratio.

3.2.4. Identification of end-members by integration of O-Sr-B-S isotopes

We use the isotopic compositions of strontium, oxygen, sulfur and boron to define the origin of different sources that affect the water quality of the river. The use of the different isotopes enables better constraints for tracing the different water sources that affect the quality of the Jordan River.

- The oxygen isotopes – In the northern zone the gradual decrease in salinity is associated with a general (although with large fluctuations) increase in $\delta^{18}O$ values (Fig. 10). In contrast, the $\delta^{18}O$ values of springs and observed runoff are low (-4‰). Hence, the oxygen isotopic modification is also inconsistent with western inflows. We observed extremely high $\delta^{18}O$ values in fishponds and in shallow groundwater below the fishpond. The large fluctuations of the $\delta^{18}O$ values probably reflect both inflows of ^{18}O-enriched groundwater superimposed with surface evaporation. Relative ^{18}O-enriched groundwater can also be derived from influence of agricultural return flow. In the southern section the $\delta^{18}O$ values show a wide range of –5‰ to –1.5‰. A large range of $\delta^{18}O$ values was also observed in the western surface inflows while groundwater show typically lower $\delta^{18}O$ values. It seems that the wide range of $\delta^{18}O$ values in the Jordan River reflect alternate contributions of groundwater (low $\delta^{18}O$) and surface water, in addition to evaporation on the Jordan River itself in the arid environment of the southern Jordan River.

- The strontium isotope variations (Figs. 14 and 15) enabled us to reveal the influence of subsurface flows in the upper (an $^{87}Sr/^{87}Sr$ decrease from 0.70775 to 0.70763) and lower (an $^{87}Sr/^{87}Sr$ increase to 0.7081 to 0.7083) sections of the river. The decrease of the $^{87}Sr/^{87}Sr$ ratios in the north is consistent with the low $^{87}Sr/^{87}Sr$ signature of the saline Yarmouk River, implying a common source for the two rivers. It should be noted that all shallow groundwater in the vicinity of the northern Jordan Valley has a low $^{87}Sr/^{87}Sr$ signature (~0.7075), which is consistent with our model of groundwater discharge and modification of the river chemistry. In the southern section the relative high $^{87}Sr/^{87}Sr$ ratio of the Zarqa River (0.7087) has only small affect on the Sr isotopic composition of the down-stream Jordan River. The $^{87}Sr/^{87}Sr$ ratio of the southern Jordan River is almost identical to that of the two identified water bodies (i.e., brines and saline sulfate-enriched groundwater) with a $^{87}Sr/^{87}Sr$ ratio of ~0.7080. This composition is also identical with that of the Lisan sediments (Stein et al., 1997), hence indicating that the Lisan Formation has a major influence on both the local groundwater and the southern Jordan River.
- The boron isotopic composition of the Jordan River ($\delta^{11}B$~30‰) is almost constant in both northern and southern sections (Fig. 16). The lack of isotopic variations is in contrast to the other chemical variations observed in the Jordan River. This implies that the different water sources has a uniform $\delta^{11}B$ composition, or some geochemical modifications have altered the original isotopic composition. In the northern section, the base saline flow has a $\delta^{11}B$ value of ~30‰ resulted from mixing of saline thermal water ($\delta^{11}B$~35-40‰, Vengosh et al., 1992) with waste water ($\delta^{11}B$~0-10‰; Vengosh et al., 1994). The saline Yarmouk River has a $\delta^{11}B$ value of 36‰, which indicates that waste water is not the only source of the groundwater. In the southern section, the $\delta^{11}B$ values of the river is different from that of the Zarqa River (25‰) but is consistent with the $\delta^{11}B$ values of the saline sulfate enriched groundwater. This composition is also identical to that of the sediments of the Lisan Formation (M. Stein,

personal communication), which again implies that boron is also derived from interaction and leaching of the Lisan Formation. Consequently, it seems that circumstances conditions resulted in similar $\delta^{11}B$ values of ~30‰, rather than modification reactions. The high correlation between elemental B and Cl also favors a conservative behavior of boron.

- The sulfur isotope variation show a large variation along the river. In the north the $\delta^{34}S$ values decrease from ~20‰ to ~5‰, together with an increase of the content of the sulfate ion in the water. This trend is consistent with the low $\delta^{34}S$ values observed in the saline Yarmouk River (-2‰), implying a common source. The low $\delta^{34}S$ values of the saline Yarmouk in not consistent with the isotopic composition of the freshwater of the Yarmouk River ($\delta^{34}S$~10‰), hence ruling out a possible model of irrigation and evaporation of the Yarmouk freshwater and formation of saline groundwater. A possible clue for the origin of the sulfate-enriched groundwater in the northern Jordan valley is the low $\delta^{34}S$ values observed in the eastern inflows, originally derived from thermal waters along the northern Jordan valley. In the southern part of the Jordan River, the $\delta^{34}S$ values of sulfate in the river (5-7‰) and associated groundwater (4-10‰) are different from that of the main gypsum layers in the Lisan Formation (14-28‰; Gavrieli et al. 1998). One significant exception is the unique low $\delta^{34}S$ value of the saline inflow of Uja-Melecha (-17‰). This low signature may reflect selective dissolution of interstitial gypsum with ^{34}S-depleted sulfate.

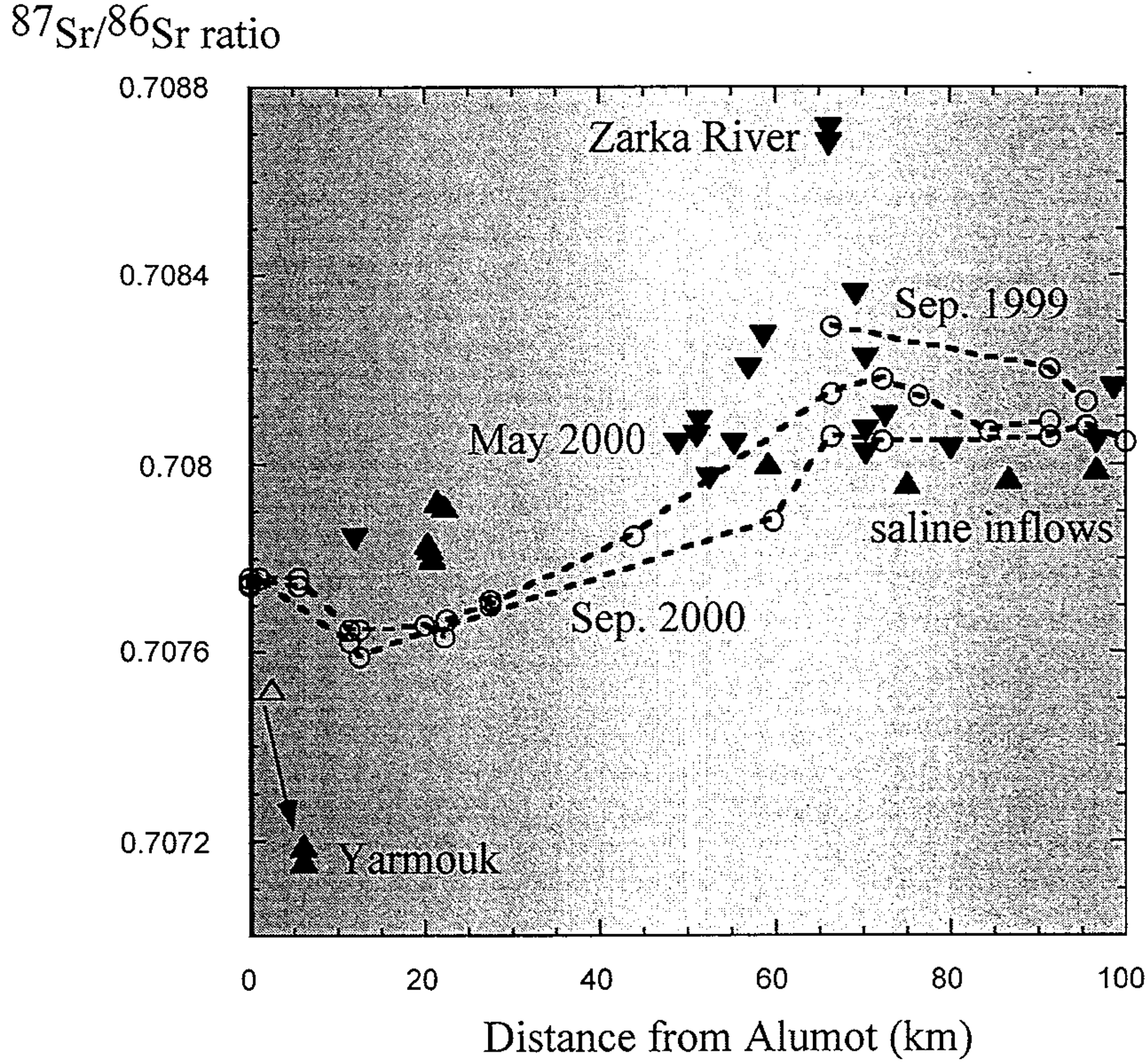


Figure 14: Distance from the origin of the Jordan River vs. $^{87}Sr/^{86}Sr$ ratios of the Jordan River (open circles in different times), western inflows (blue triangles), and eastern inflow (red triangles). Note the relatively low $^{87}Sr/^{86}Sr$ ratios of the both fresh (open triangle) and saline Yarmouk River, and the high $^{87}Sr/^{86}Sr$ ratios of the Zarka River. The $^{87}Sr/^{86}Sr$ of the Lisan formation is ~0.7080.

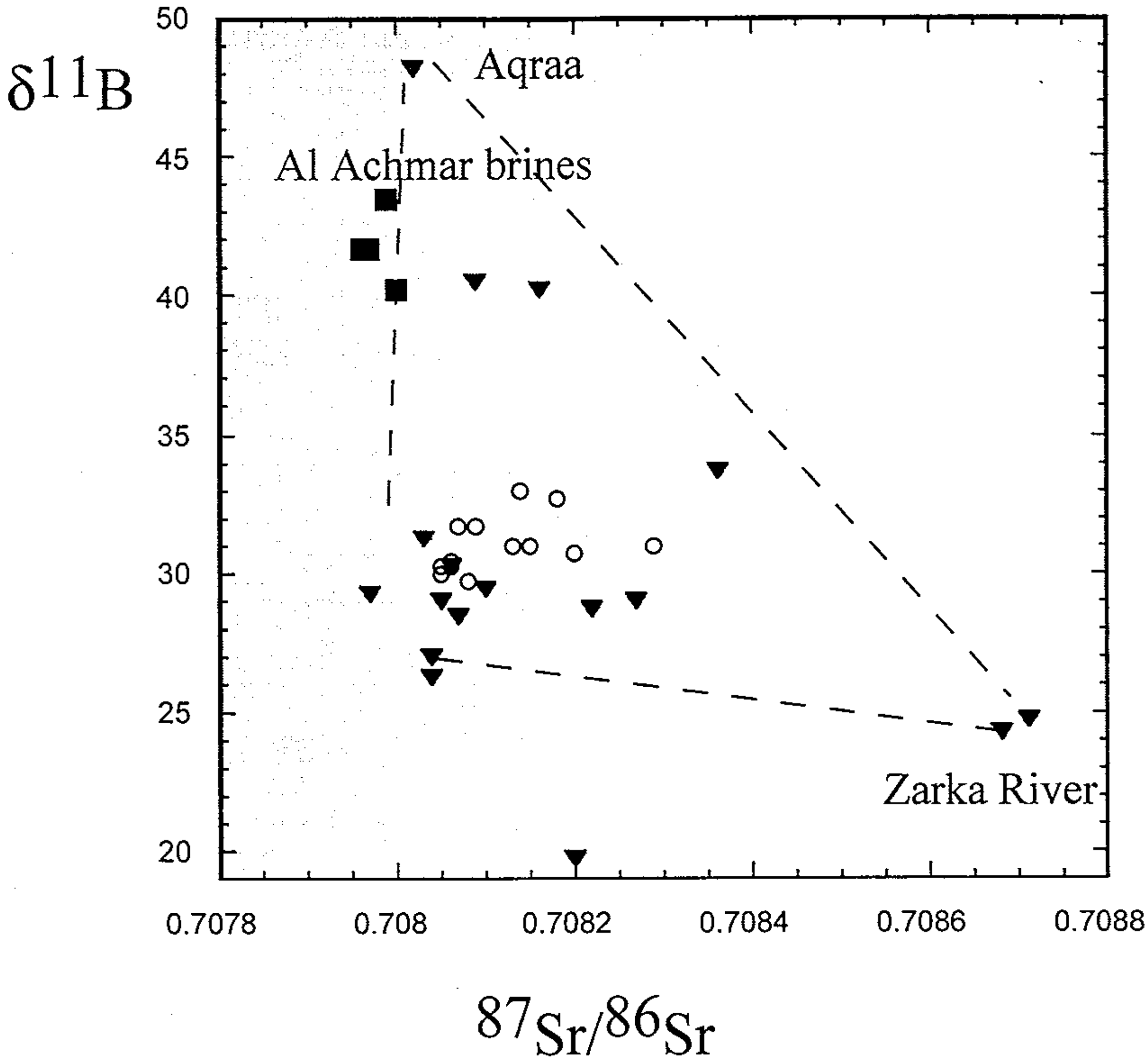


Figure 15: Variations of $^{87}Sr/^{86}Sr$ vs. $\delta^{11}B$ values of the Jordan River (open circles) and tributaries (eastern in red triangles, western in blue squares) in the southern area of the Jordan River. The variations reflect contribution of three components, in which it seems that the influence on the isotopic composition of the Jordan River is predominant by the saline sulfate-enriched eastern inflows, apparently derived from interactions with the Lisan Formation.

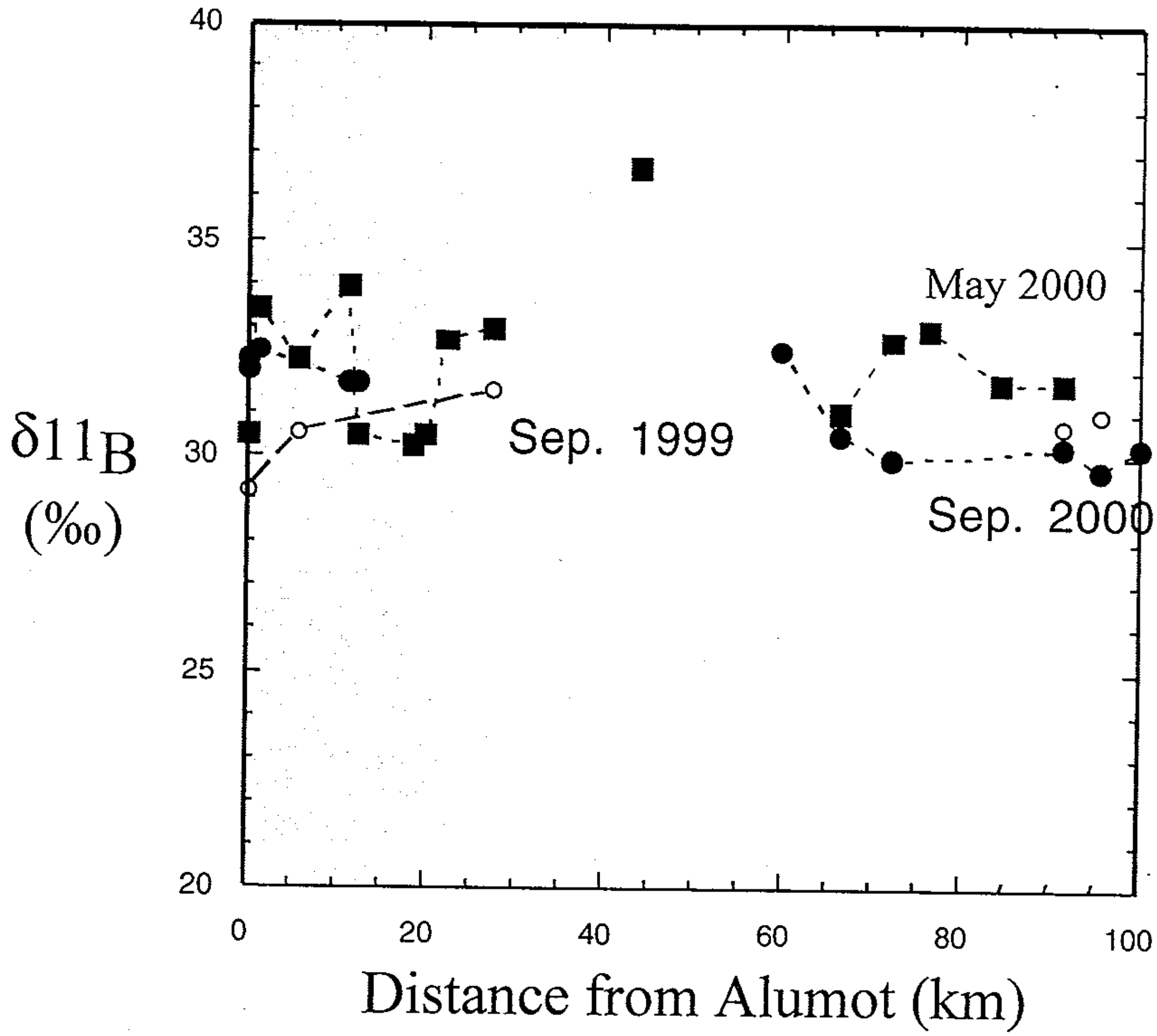


Figure 16: Variations of $\delta^{11}B$ values with distance from the origin of the River. The relative constant $\delta^{11}B$ values along the flow of the river is in contradiction to the large chemical variations, reflecting different sources with a uniform $\delta^{11}B$ value of ~30‰.

3.3. INFLOWS FROM THE WEST BANK

3.3.1. Wadi El Maleh:

Wadi El Maleh is located in the northern part of West Bank, the surface catchments area is about 309 square km. This catchments area located in semi-arid climate zone with annual rainfall of about 350 mm in the western part and decrease to about 200 mm in the eastern part which is closed to the Jordan River. Only with rainfall intensity of more than 30 mm during 48 hours, if this happen in the western part of the catchments area, the flooding will take place

The historical data of the springs discharge sort between 10 liter/second in a drought year like in the hydrological year 79/80 and 80.39 liter/second during the hydrological 93/94. Water from Maleh springs flow eastwards and partially infiltrate through the alluvial deposit of the Wadi and the rest contribute the Jordan River. During the next stage of the research it is important to calculate the amount of water discharge to the Jordan River. Indirect recharge takes place along the Wadi floor where surface water (Maleh water) infiltrate into the shallow aquifer system (gravel and conglomerate). The Jordan River is base level for the groundwater flow regime in the Jordan Valley, so the contribution of Wadi El Maleh on the quality of the Jordan River Water Quality should be examine.

Site	Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Maleh	99/00	15.8	22.5	16.0	27.0	26.9	32.0	17.0	25.8	25.0	24.0	21.5	24.0	277.5
	00/01	25.6	23.0	22.5	27.8	20.5	18.7	16.8	16.6	14.9	13.6	13.0	12.0	225.0
	O1/02	11.5	18.9	24.5	28.5									

Table 8: Discharge of Wadi El Maleh springs up-stream in liter per second (l/s)

This springs group issue along the Wadi floor, which follows in the reality a structural feature (El Maleh fault). During springtime and early summer additional springs issue at relatively higher level, these springs are disappeared at the end of Jun. By observation the locations of the springs discharge niches, we found that the location of these springs were 10 meter higher than the present discharge site. This means that the regional groundwater table was higher than the present one. At the old spring niches precipitation of travertine (calcium carbonate) could be recognize whereas new precipitation of calcium carbonate are not present. In general the discharge of Wadi

El Maleh springs depend partially on the rainfall, this can be notice by the discharge hydrograph. Additional deep water from the deep aquifer system circulated upward along the fault and mixed with the freshwater. Sodium/chloride ratio in the water is about 0.6 whereas the bicarbonate is 238 mg/l.

3.3.2. **Wadi El Quilt**

The catchment area of this wadi extends from the mountain area in the West (Ramalah-Jerusalem) to the Jordan River in the West. High annual rainfall characterizes the western part of the catchment area (600 mm) whereas low rainfall of about (150 mm) characterizes the eastern part. The spring discharge (three springs), which drains in Wadi El Quilt chanal, is important for people in the southern part of Jericho city and to people in Aqbat Jaber refugee camp. The canal water is used mainly for irrigation, livestock and during drought years for human consumptions.

Flooding water during months is not less important than spring water because most of the groundwater wells (shallow wells) are depending for groundwater recharge on the infiltration rate from flooding. The quality of these wells (in Jericho area) and as consequence their uses govern mainly through the recurrence and amount of the floods. During the last year, floodwater samples were collected and analyzed.

Three hydrological features characterizes this Wadi which are:

1- Three main springs issue up-stream (Quilt, Al Fawwar and Al Farah). These springs issue from carbonate rocks of Turonian age.
2- Water from these spring drain in cement canal (called Wadi El Quilt canal) to southern part of Jericho city and to Aqbat Jaber refugee camp. This water use mainly in irrigation.
3- During wintertime and after heavy rainfall in the mountain area (in Ramalah and Jerusalem) floodwater flow in the Wadi. Due to technical problem it was not possible to measure the flooding discharge with the available instrument (current meter) and it is also to emphasis that the flooding events happen suddenly.

*Table 9: shows the average monthly discharge of the springs during the drought hydro-logical year 1978/1978 and the wet year 1991/1992 in liter per second (l/s) *.*

Site	Year	Oct	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul	Aug.	Sep.
Quilt	78/79	60.9	67.2	65.6	54.0	99.4	63.2	68.3	68.6	59.3	60.7	56.5	55.3
	91/92	64.1	62.7	1005.7	1927.2	2512.2	2445.7	1699.4	887.8	427.6	358.7	282.0	244.0
Al Fawwar	87/79	0.0	0.0	0.0	0.0	52.6	8.8	25.2	0.0	0.0	0.0	0.0	0.0
	91/92	0.0	0.0					1067.0	566.3	250.8	196.3	140.2	129.5
Al Farah	90/91					122.2		37.0	39.5	34.6	27.8	32.5	26.4
Quilt canal	78/79	61	67	66	54	99	63	68	69	59	61	57	55
	91/92	64	63	1006	1927	2512	2446	1699	888	428	359	282	244

* Source of these data is the Palestinian water authority

Table 9 shows that the discharge of Wadi El Quilt spring is strongly govern through the annual rainfall, which cause a fluctuation in the discharge. Water in the canal originates mainly from El Quilt spring and partially from Al Fawwar spring. Water samples were collected from Wadi El Quilt canal and analyzed for its chemical constituents. The influence of Wadi El Quilt canal on the quality of the Jordan River is mainly through agricultural return flow as well as through canal and ponds leakages. Figure 18 shows the concept of the influence of Wadi El Quilt on the water quality of the Jordan River.

3.3.3. Wadi El Faria

This wadi locate in the northern part of the West Bank between 190 and 200 east longitude and 160 and 195 north latitude (according to the local grid). The catchment area of this Wadi is 330 square km and extend from Nablus city in the northwest to the Jordan River in the east. The northwest-southeast extension of the catchment area , the annual rainfall decrease from 508 mm in Talluza to 230 mm in the eastern part of the wadi (El Faria agricultural station). The eastern part of Nablus building up area related to the catchment area, so municipal untreated wastewater originated mainly from houses and small industrial enterprises flow northward in Wadi El Sajor and turned eastwards joining the main flow system with freshwater (wadi El Bathan and El Faria springs groups). The main industrial activities in Nablus are food processing, plastic products, stone cutting, olive oil pressing and bricks. Additional waste water discharge come from Asker and Balata camps which are located in the eastern part of the city and have their owe sewers system. As a result the Wadi start with untreated waste water (see conceptual model Figure 19).

The population of Nablus city was in 1999 100,000 inhabitants, half of them are living in building up areas related to Wadi El Faria catchment area. The average daily consumption is 80 liter, so it is expected that about 4000 cubic meter discharge daily in the wadi. It is also expected that about 20% of the wastewater infiltrate through the sewer system, so 3200 cubic meter expect to flow in the Wadi. Additional non calculate waste water discharge into the wadi from septic tanks which transport waste water from septic tanks. After 4 km flow, fresh water originate from El Sybian spring discharge into the system. The mixed water flow northwards and additional fresh water join he system at Al Twaheen sampling site (Wadi El Bathan springs group). After 3 km northward additional fresh water from El Faria spring group join the wadi (sampling site El Malagee). From this site the wadi flow eastward and additional fresh water from El Miska and Shibli springs join the system with a distance of 8 and 10 km respectively (from El Malagee sampling site).

Five main spring groups issue at different elevation with a total annual discharge of 13.5 MCM. The highest discharge was measured during March and April with 1.41 and 1.38 MCM and the lowest discharge was in October. Spring group I, II and III issue from the Jenin Sub-series (chalky limestone) of Eocene age where spring groups IV and V discharge from the Beida formation (conglomerate) of Neogen age.

Figure 17: Conceptual Model for Wadi El Maleh flow system in West Bank

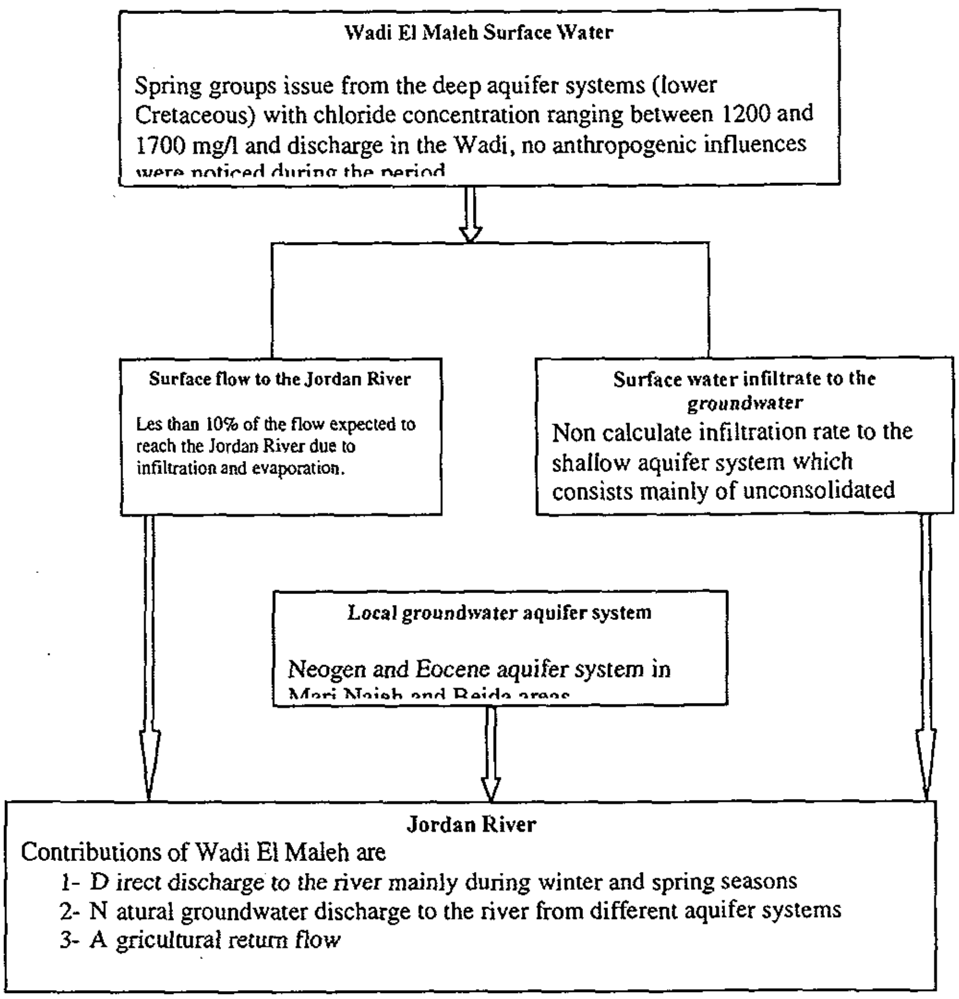


Figure 18: Conceptual Model for Wadi El Quilt system in West Bank

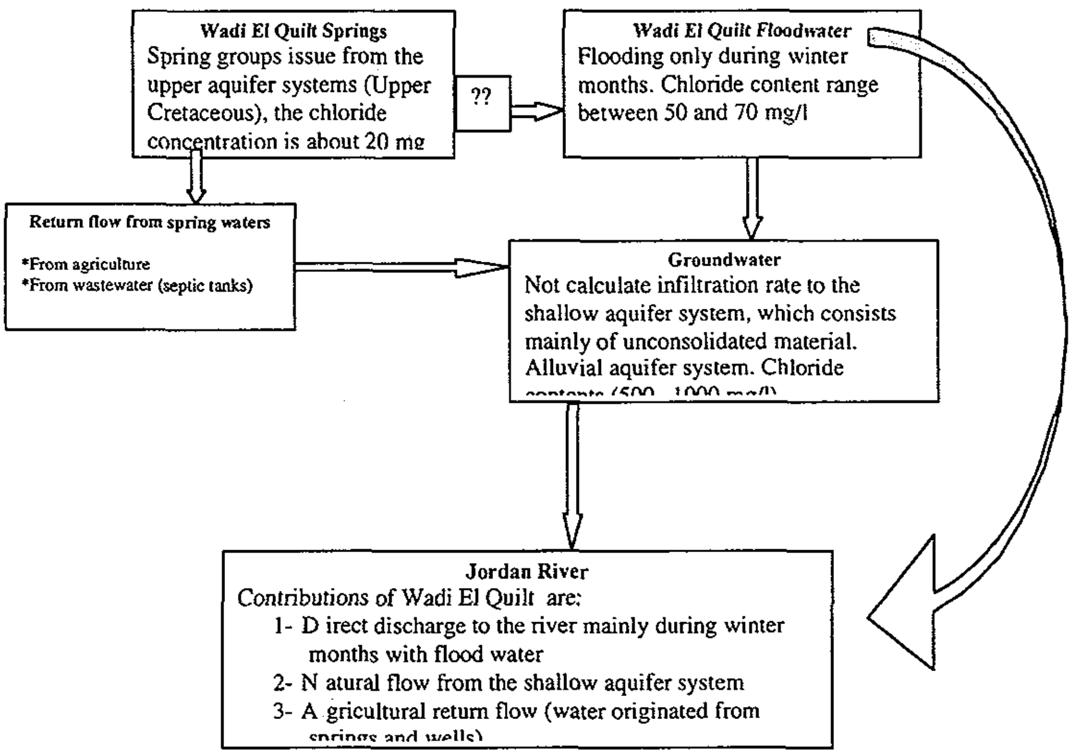
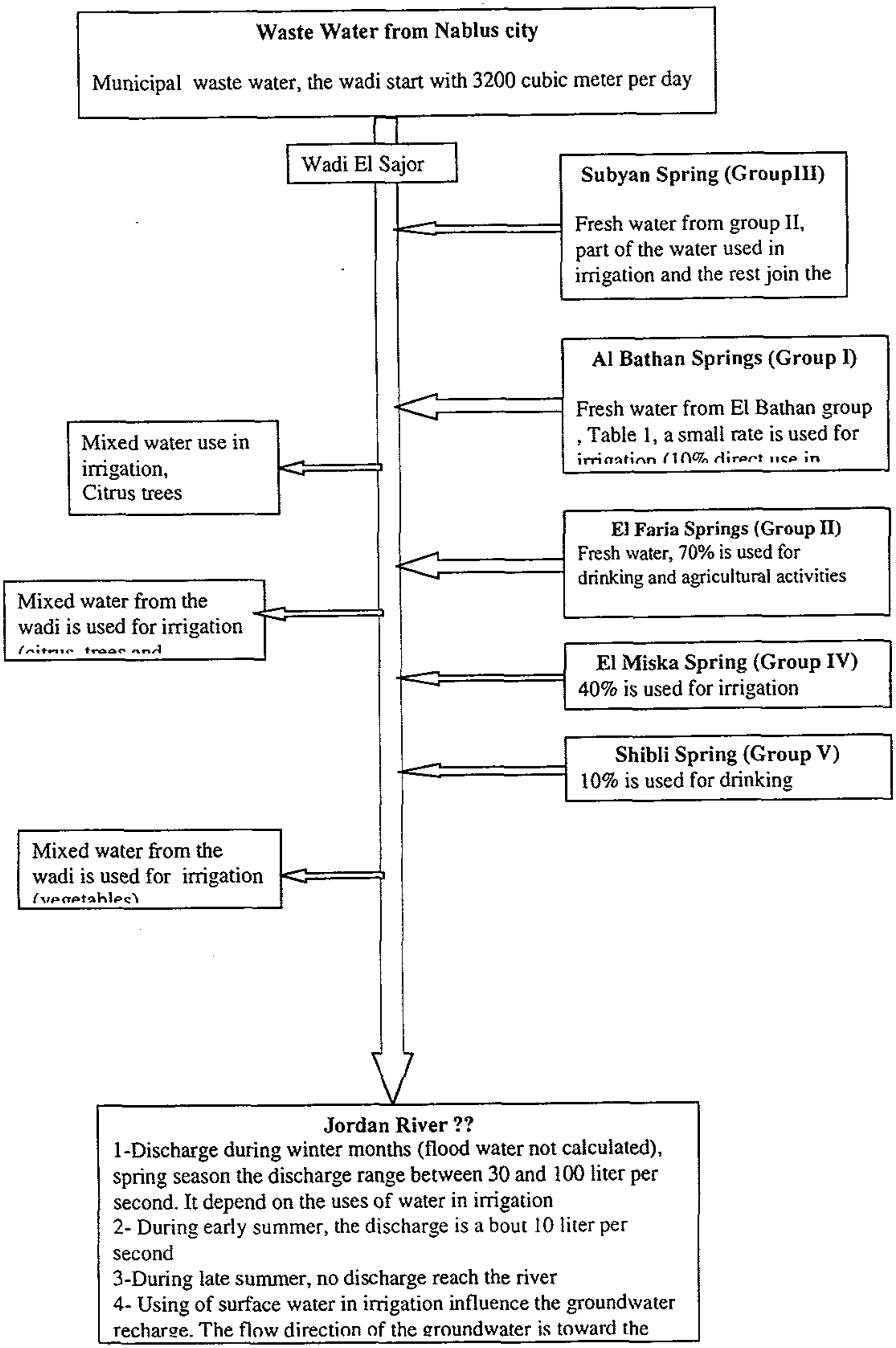


Figure 19: Conceptual Model for Wadi El Faria flow system-West Bank



3.4. CONCLUSION

Our study shows that the quantity and quality of Jordan River water is shaped by continued groundwater discharge, in addition to tributary inflows to the river. The impact of the groundwater component on the quality of the Jordan River is a major constraint for future management of the river and implementation of the Peace Treaty between Israel and Jordan. Future elimination of the saline inflows (such as the saline carrier) and sewage dumping and further exploitation of the river, as suggested in the peace treaty would further increase the impact of the subsurface flow and result in further deterioration of the ecological system of the river. In the south it would imply that salinity levels would increase beyond that observed today. This would have severe ramifications for the region's future economic livelihood, political stability, and cultural importance. Beyond that, reduction of the Jordan River flow will further enhance the rate of the Dead Sea water level drop of the. The future of the Jordan River therefore rests upon the amount of groundwater discharge it receives. Given the reduced freshwater inflow, the Jordan River has become a drainage system rather than an ordinary river.

4. Scientific Impact of Cooperation

The scientific collaboration during the second year of the project focused on coordination and simultaneous sampling campaigns of all teams, exchange of water samples for laboratory assurances and using each other unique resources, and data interpretation. In addition, the participants shared their knowledge in sampling procedures, discharge measurements, and laboratory analyses. The location of the Jordan River as a border between Israel and Jordan requires special cooperation between the parties involved. Consequently, the full assessment of the salt budget and water quality of the river requires integration of inflows from both sides of the river, thus emphasizing the importance of collaboration. The mass-balance measurements and calculation was based on simultaneous Jordanian and Israeli measurements at both sides of the river.

5. Description of Project Impact

According to the regional peace agreements, both sewage water and water from the saline carrier will be treated and reused. Carrying out these agreements will result in a dramatic reduction of input flow rates into the river. Under these circumstances the almost only available source will be rare floods, drainage and groundwater flow entering the river. Our results demonstrate that groundwater inflow have an important contribution to the quality of the Jordan River even in the present conditions. The implications of these results has significant consequences for the future of the river. Future treatment and elimination of surface inflows (e.g., eliminate the discharge of saline water from the Saline Carrier, better treatment of the sewage effluents) may reduce the surface inflow but the impact of groundwater discharge will increase. Moreover, contamination of local groundwater may have also affect the river, thus remmediation of the river will require an overall approach that includes also prevention of the contamination of the local groundwater.

6. Strengthening of Middle Eastern Institutions

In **Department of Geological and Environmental Sciences at Ben Gurion University** we installed the analytical apparatus for chemical separation of Sr and NO_3 for isotopic analyses. This included purchasing a bio-hazard fume-hude (to isolate Sr from possible contamination) and establishing ion-exchange columns for separation of the elements before isotopic analyses. The procedure was tested by strontium isotopic measurements at the Isotope laboratory of US

Geological Survey (Menlo Park, California) and was find indistinguishable from the separation experiments carried out at USGS. We also purchased heating unit and mobile spectrophotometer for COD measurements.

In Al-Quds Unviversity we upgraded the existing instruments to accommodate the needs of the project. Major cations and anions, BOD, COD and Fecal coliform are measured at the central laboratory of Al-Quds University. We expect to purchase further items to fully accommodate special chemical requirements for field and laboratory measurements.

In the Division of Geochemistry and Environmental Geology in the Geological Survey of Israel, the building of a clean laboratory is completed. The laboratory began using the Multi-Collector ICP- mass spectrometer (MC-ICP-MS) that was installed in the GSI on September 2000. This has put the GSI in the forefront of isotopic- geochemical studies in the world and provide better performance of the isotopic tasks of this project.

At the Technion we have constructed the set-up and developed the procedures of flow rate measurements at river sections and side tributaries. Our team have developed the know-how and a good understanding of the field conditions around the Jordan River sites. We have developed the methodology to deal with the complex water and chemical mass balance calculation using matrix solvers with a flexible degrees of freedom. An error analysis was obtained.

7. Future work

Since we have been generated extensive hydrological and geochemical data during the first two years of the project, we expect to further evaluate our database. In addition, we intend to complete some of the isotopic measurement for better understanding and evaluation of the information. Further evaluation of the data will enable us to establish more reliable mass-balance calculations and further constrain and estimate the groundwater discharge into the Jordan River. We will continue to integrate the hydrological and geochemical data for establishing a general model for the water quality of the Jordan River.

Section II: Project Management and Cooperation

1. Managerial Issues

Budget

During the second year of the project the management work included budget acceptances and distribution by Ben Gurion University. BGU received from US-AID a total payment of $348,536, which was distributed as follows:
ECO and University of Jordan – $106,087
Al Quds University – $55,267
Technion – $53,584
Geological Survey - $65,629
Ben Gurion University -$67,969

Staff

The Israeli team: As part of the project three research students from different institutions continued to work on their projects:

- Mr. Ran Holtzman, a M.Sc. student from the Technion is working on mass-balance modeling of the salt budget of the river.
- Ms. Efrat Ferber, a M.Sc. student from Ben Gurion University is working work on the hydrochemistry and isotope geochemistry of the Jordan River system.
- Ms. Michal Segal, a M.Sc. student from the Technion is working on the sources of nitrogen in the Jordan River and processes that are affecting the nitrogen distribution in the river.

The Jordanian team: Students are now being involved in the study either entirely within the project, or partially in connection with other projects. These students are:

- Ms. Khalida Abu Makhlouf,
- Ms. Sams El Din Fehdi
- Ms. Husam Sarahna.

2. Cooperation, Travel, Training and Publications

During the first year of the project, during most of 2000, we conducted several meetings on different level. Since the beginning of Al-Aqtza events on October 2000, we were not able to meet as frequently due to security reasons. The communication, however, continued extensively through phone calls and electronic mail.

Project Meetings during 2001:

1. A working meeting at Tuscany, Italy: April 2001.
   Participants are: Dr. A. Marie, Dr. A. Vengosh.

2. An annual meeting of all the partners involved at Larnaka, Cyprus, February 14-16 2002. Participants are: Prof. E. Salameh, Dr. R. Daud, Dr. U. Shavit, Dr. I. Gavrieli, Dr. A. Vengosh, Mr. R. Hotzman, Ms. E. Ferbar, and Ms. M. Segal.
   The meeting included summary of up-to-date results and preparation for the annual report.

Fieldtrips to the Jordan valley

1. January 14-15th, 2001: Sampling of the upper section of the Jordan River– the Israeli team (BGU, Technion, GSI).
2. February 27-28th, 2001: Flow measurements and sampling of inflows of both sides of the Jordan River and the different sites along Jordan River – the Israeli (BGU, Technion, GSI) and Jordanian teams.
3. March 28-29th, 2001: Flow measurements and sampling of inflows of the western side of the Jordan River and the different sites along Jordan River – the Israeli (BGU, Technion, GSI) team.
4. April 22-23rd, 2001: Flow measurements and sampling of inflows of both sides of the Jordan River and the different sites along Jordan River – the Israeli (BGU, Technion, GSI) and Jordanian teams.
5. June 4-9th, 2001 : Flow measurements and sampling of inflows of both sides of the Jordan River and the different sites along Jordan River – the Israeli (BGU, Technion, GSI) and Jordanian teams.
6. August 3, 12 and 21st, 2001: Flow measurements and sampling of inflows of both sides of the Jordan River and the different sites along Jordan River – the Israeli (BGU, Technion, GSI) and Jordanian teams.

Publications and participation in international conferences

Bullen,T.D., Daoud, R., Gavrielli, I., Marie, A., Salameh, E., Shavit, U. and Vengosh, A., 2000. The importance of ground- and surface water contributions to the Jordan River: a collaborative hydrologic, geochemical and isotopic study. EOS, v. 81, n. 19, p. S219.

Shavit, U., Holtzman, R., Segal, M., Vengosh, A., Farber, E., Gavrieli, I., Bullen, T., and ECO-Research Team, Water Sources and Quality Along the Lower Jordan River, A Regional Study, in *Preserving the Quality of our Water Resources*, Springer-Verlag , 2001.

Shavit U, Holtzman R, Segal M, Vengosh A, Farber E, Gavrieli I, ECO RT, and Bullen T, Water Sources and Quality Along the Lower Jordan River, A Regional Study, 4th Symposium cum Industrial Forum, Preserving the Quality of our Water Resources, Vienna (Austria), pp 95-102, 23-25 April 2001.

Vengosh, A., Farber, E., Shavit, U., Holtzman, R., Segal, M., Gavrieli, I., Bullen, T.M., (2001). *Exploring the sources of salinity in the Middle East: A hydrologic, geochemical and isotopic study of the Jordan River.* In: Cidu, R., *Proceeding of the Tenth International Symposium on Water-Rock Interaction, WRI-10*, Villasimuis, Sardinia, Italy, June 2001; (keynote lecture), Vol. 1, 71-79, A.A. Balkema Publishers.

Vengosh, A., Farber, E., Shavit, U., Holtzman, R., Segal, M., Gavrieli, I., Bullen, T.M., and Mayer, B. (2001). *Tracing the origin of salinity of the Jordan River.* 4th International Symposium on Applied Isotope Geochemistry, June 25-29, 2001, Pacific Grove, California, USA, pp. 162-164.

Vengosh, A., Farber, E., Shavit, U., Holtzman, R., Segal, M., Gavrieli, I., Bullen, T.M., and Mayer, B. (2001). *What Science can contribute for future cooperation in the Middle East: The Jordan River.* American Water Resources Association, International Specialty Conference on *Globalization and Water management: the Changing Value of Water.* August 6-8, 2001, Dandee, Scotland, UK.